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Joint German-Indonesian Seminar on Public Acceptance, Waste-Management, and Nuclear Safety

Jakarta
October 7–9, 1986

GERMAN-INDONESIAN COOPERATION
IN SCIENTIFIC RESEARCH AND TECHNOLOGICAL DEVELOPMENT

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JOINT GERMAN-INDONESIAN SEMINAR ON PUBLIC ACCEPTANCE, WASTE-MANAGEMENT, AND NUCLEAR SAFETY

JAKARTA
October 7–9, 1986

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Introduction

Within the Governmental Agreement on Cooperation in Scientific Research and Technological Development signed between the Republic of Indonesia and the Federal Republic of Germany on March 20th, 1979, a Special Agreement on Cooperation in the field of Nuclear Energy was concluded on October 29th, 1982, between the National Atomic Energy Agency (BATAN) and the Kernforschungs-anlage Jülich GmbH (KFA Jülich).

During the first German-Indonesien" Workshop on Nuclear Power Technology" in January 1984 and in subsequent discussions between the Research Ministries of the Federal Republic of Germany and the Republic of Indonesia it was agreed to hold a second Seminar on "R &6 D Activities Using the MPR-30" which took place in August 1985, and a third Seminar on" Public Acceptance, Waste Management, and Nuclear Safety" which was held in October 1986.

The aim of the third seminar was to convey the experience and knowledge gained on both sides in their attempts to explain technical matters, especially those related to engineered safety to the broad public. This Seminar, although being planned as much as four years back, reached special significance and impact after the accident in Tschernobyl.

The seminar took place October 7 - 9, 1986 in BATAN's head-quarters in Jakarta before a broad audience. In presentations from both the Indonesian and the German side an overview was given in the areas of

Public Acceptance
Waste Management
Nuclear Safety.

The lectures presented by both sides are compiled in these proceedings with the aim of further disseminating their contents thus helping BATAN to assess the possibility of introducing those R & D activities pertinent to the country's development.

The present publication is edited by the International Bureau of KFA Jülich compiling the manuscripts submitted by the authors.

JOINT GERMAN-INDONESIAN SEMINAR ON

PUBLIC ACCEPTANCE, WASTE MANAGEMENT, AND NUCLEAR SAFETY

JAKARTA, 7 - 9 OCTOBER, 1986

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INDONESIA-GERMANY SEMINAR

on

PUBLIC ACCEPTANCE, WASTE MANAGEMENT, AND NUCLEAR SAFETY

Jakarta, 7 - 9 October, 1986

Tuesday, 7 October, 1986

09.00 - 09.30	Opening Ceremony: 1. Address by BMFT/KFA Representative 2. Address by the Director General of BATAN
09.30 - 09.45	Coffee break
Technical Session I	Chairman : Iyos R. Subki Co-chairman : D. Nentwich Rapporteurs : Setyo Utomo Said Sedyatmo
09.45 - 10.15	BATAN's activities on Public Relation S. Soeprapto et al.
10.15 - 10.30	Discussion
10.30 - 11.15	Decision making in energy policies with conflicting interests O. Renn
11.15 - 11.30	Discussion
11.30 - 12.15	The development of public opinion on nuclear technology in the Federal Republic of Germany H. Grupe
12.15 - 12.30	Discussion
12.30 - 13.00	Lunch break
Technical Session II	Chairman : W. Kölzer Co-chairman : Sutarjo Supadi Rapporteurs : Sedyatmo Setyo Utomo Said
13.00 - 13.45	Problems on acceptance of nuclear energy roots, development, and varieties in different countries E. Muench
13.45 - 14.00	Discussion
14.00 - 14.45	Public relation activities of the Karlsruhe Nuclear Research Centre contributions to opinion forming by a national research centre K. Koerting
14.45 - 15.00	Discussion
15.00 - 15.15	Coffee break
15.15 - 16.00	Experiences of a newspaper journalist with the official information policy of nuclear facilities H. Koppelstaetter
16.00 - 16.30	Discussion on Public Acceptance

Wednesday, 8 October, 1986

Technical Session III

Chairman : G. Schultheiß
Co-chairman : Soedyartomo Soentono
Rapporteurs : Sofyan Yatim
Asmedi Suripto

09.00 - 09.45	BATAN's activities in Waste Management Soeroto Ronodirdjo
09.45 - 10.00	Discussion
10.00 - 10.45	Factors to be considered in the establishment of a radwaste management system H. Krause
10.45 - 11.00	Discussion
11.00 - 11.15	Coffe break
11.15 - 12.00	Principles of and experience in low level, medium level and tru element bearing radioactive waste treatment H. Krause
12.00 - 12.15	Discussion
12.15 - 12.45	Lunch break

Technical Session IV

Chairman : Suwarno Wiryosimin
Co-chairman : G. Philip
Rapporteurs : Asmedi Suripto
Sofyan Yatim

12.45 - 13.30	Characterization of low and intermediate level waste forms - qualification for interim storage, transport, and disposal. R. Koester
13.30 - 13.45	Discussion
13.45 - 14.30	Disposal strategies for radioactive waste - experience in the Federal Republic of Germany H. Stoeber
14.30 - 15.00	Discussion on Waste Management
15.00 -	Coffee

Thursday, 9 October 1986

Technical Session V		Chairman H. Krause Co-chairman : M. Hasroel Thayib Rapporteurs : Hudi Hastowo M. Salman Suprawardhana

08.30 - 09.00	BATAN's activities in Nuclear Safety R.P.H. Ismuntojo & Suharno
09.00 - 09.15	Discussion
09.15 - 09.45	Nuclear Safety Research in the Federal Republic of Germany - contribution to the licensing process and to plant performance H. Kollath
09.45 - 10.00	Discussion
10.00 - 10.15	Coffee break
10.15 - 10.45	Ergonomics in nuclear safety - human factors engineering E. Muench
10.45 - 11.00	Discussion
11.00 - 11.30	Roles of standards and codes in enhancing nuclear safety G. Philip & W. Schwarzer
11.30 - 11.45	Discussion
11.45 - 12.30	In-service inspection: contribution to plant reliability and safety G. Schultheisz
12.30 - 12.45	Discussion
12.45 - 13.15	Lunch break

Technical Session VI		Chairman : Boedi Soedarsono Co-chairman : E. Münch Rapporteurs : Djodjo Arifin S. Kustiono

13.15 - 13.45	Probabilistic risk analysis for nuclear power plants U. Hauptmanns
13.45 - 14.00	Discussion
14.00 - 14.30	Major reactor incidents and consequences J. Wolters
14.30 - 14.45	Discussion
14.45 - 15.15	Emergency planning and preparedness for nuclear facilities W. Koelzer
15.15 - 15.30	Discussion
15.30 - 15.45	Coffee break
15.45 - 16.15	Environmental monitoring of nuclear facilities - a contribution to environmental safety and public acceptance of nuclear activities W. Koelzer
16.15 - 17.00	Discussion on Nuclear Safety

Opening Remarks on the German-Indonesian Seminar on Public Acceptance, Nuclear Safety and Waste Management.

Jakarta, 7.-9.10.86.

D. Nentwich
International Bureau
KFA Jülich

This is already the third occasion, on which experts from the Federal Republic of Germany and the Republic of Indonesia gather in a seminar to present the state of art of research and technology within their respective country and domain and which serve to exchange views of newest developments and to possibly find ways and means of establishing joint collaborative efforts. The first seminar was held in August 1984, giving a general overwiew of nuclear activities in both our countries. You may judge by yourself the political importance attached to that seminar by our respective governments when I recall to your memory that it was opened by our Federal Minister for Research and Technology, Dr. Heinz Riesenhuber, whereby the scheduled participation of Minister Prof. Habibie had to be postponed at shorthand notice due to other non-forseeable obligations. As one outcome of this seminar, both sides agreed to hold further ventures of this kind, recognizing these occasions as a valuable instrument to establish close bilateral contacts.

The second seminar took place almost exactly one year later in August 1985. Reflecting the explicit wishes of BATAN it concentrated on reviewing R+D activities using neutrons as a research tool and served also to provide a forum of discussion between the experts of both sides to evaluate the possibilities of jointly implementing projects of mutual interest utilizing the MPR 30 as a neutron source. As I see it, this seminar has shown outstanding results by reaching agreement in the following areas:

1. Following expert input from the German side, BATAN has theintention of concentrating future R+D activities on materials sciences using neutron scattering techniques, an area of high interest to the German side,too. Based on first recommendations of Prof.Springer from Jülich and of Prof. Schmatz from Karlsruhe, Dr.Werner from Jülich has in the meantime undertaken the noteworthy task of specifying in considerable detail the technical outlines of the experimental hardware. In order to also create the necessary human resources on the Indonesian side to gradually independezise this research, Prof. Schmatz and Dr. Werner gave a series of lectures over a fortnight in Bandung in July of this year on the basic of physical principals of neutron scattering. Participants to this venture were young scientists from BATAN and graduates from Indonesian universities who will hopefully have the chance to use later on the acquired knowledge within BATANs research programmes. Needless to say that we have also initiated training programmes for BATAN personnel in German research institutions: Three BATAN employees are presently undergoing training within the IAEA fellowship programme.

2. Furthermore, the German and Indonesian side agreed to initiate a fuel development programme including irradiation tests. In a first step, BATAN will fabricate fuel pellets from natural Uranium with the existing facilities at Bandung

in order to have first inserts ready when the MPR 30 becomes serviceable. Later on, inserts with enriched Uranium and PWR dimensions will be produced. Together with this it is planned to extend the hardware ordered already with the MPR 30 constructor so as to include an out-of-pile loop where the safe handling and insertion of the irradition capsules can be practised prior to the insertion in the in-pile loop. Following the seminar, a joint programme steering committee comprising high-ranking officials from both sides was established, which in turn was followed by the visit of BATAN representatives to Germany in October 1985 when a detailed programme schedule was discussed and pinpointed. Programme activities started in April 1986 with the training of 4 BATAN employees in all relevant areas of irradiation test lay-out and performance. A further BATAN employee took up his training in quality control activities concerning pellet manufacture in September 1986.

3. The 1985 seminar was also the starting point for jointactivities concerning the safe and reliable operation and maintenance of the MPR 30 as a neutron source for the joint R + D projects. Based on an industrial training programme for reactor operators an agreement was reached to delegate an experienced shift leader from KFA to BATAN to advise and guide BATAN personnel in pre-operational training schemes and in giving a hand after the MPR 30 comes on line. This expert is just now taking up his activities. Still open for discussion with the BATAN management is the training of the service personnel that is to safely manage the experimental hardware under request from the scientific user community. Taking into

consideration the presently valid time schedule for the commissioning MPR 30, we have the firm opinion that activities in this area are lagging and should be implemented as soon as possible.

Now let me come to the third joint seminar which has just started. Topical issues to be delt with are public relation activities and the lessons we have learned concerning the controvertial situation in our country with regard to nuclear energy; nuclear safety issues which naturally play a central role in this controversy and which after Chernobyl have reached a new dimension; and last but not least the wide area of waste management, where at least in our country a lot of things are left to be done, not because our engineers did not offer adequate and safe technical solutions, but because politics could not be able formulate the objectives to be reached. We feel sure that the experience displayed here in the next 3 days will give BATAN an ample picture of the issues on hand and which might serve to cope with the one or other similar situation in this country. Needless to say that we offer our cooperation after and beyond this seminar in all those technical areas where a common interest might be found, the same as we have done in the preceeding ones.

Please don`t let me close these opening remarks without saying that at least as far as the large number of seminars that I have organised with our partner countries around the world in the past 12 years we have introduced a novalty and I am particularly grateful to Dr. Körting for having made the first suggestion. With Mr. Koppelstätter we have a young journalist amongst our lecturers who, in the strict sense, does not belong to any given scientific community and who in our country has acquired the reputation of being able and willing to report in the press on nuclear issues in an objective and matter-of-fact manner. I am particularlay looking forward to his point-of-view from across the fence.

In closing I would like to extend my best wishes for a successful and informative seminar to all lecturers and participants.

"PUBLIC INFORMATION ACTIVITIES IN THE NUCLEAR ENERGY PROGRAM IN INDONESIA"

Experience and Future Program

by

S. SOEPRAPTO, HERYUDO KUSUMO, ARIFIN S. KUSTIONO

BADAN TENAGA ATOM NASIONAL

INDONESIA - GERMANY SEMINAR
ON
PUBLIC ACCEPTANCE, WASTE MANAGEMENT AND NUCLEAR SAFETY
JAKARTA, OCTOBER 1986

"PUBLIC INFORMATION ACTIVITIES IN THE NUCLEAR ENERGY PROGRAM IN INDONESIA"

Experience and Future Program

Introduction

The activities in nuclear field in Indonesia started in 1954 when the Government appointed a state Committee for the Investigation of Radioactivity. The task of this Committee was to investigate the effects of radioactivity to the people of Indonesia caused by nulear tests carried out in the Pacific, to make a study on atomic energy as a new energy source for the development of the nation and to inform the public concerning the consequences of peaceful and non peaceful uses of atomic energy. With the Government Regulation No. 65 year 1958 the Institute for Atomic Energy was founded in 1958 and later on became the National Atomic Energy Agency (BATAN) as the Law on Atomic Energy was enacted in 1964.

The main objective of the Indonesian Nuclear Programme is to promote the peaceful uses of atomic energy in various fields such as agriculture, medicine, industry and electric power generation.
The first research reactor Triga Mark II was built in Bandung and in operation in 1965 and another reactor was built at Jogyakarta in 1979. Henceforth the research activities and application of radioisotopes supplied by the Triga Reactor developed rapidly.
Since 1968 Indonesia has been considering nuclear energy as an option for the supply of energy for electric power, as a series of Seminars and Workshops had been carried out on several aspects of interest including the public appraisal of nuclear energy.

A nuclear power planning study was carried out on Indonesia with IAEA in 1975 and then followed by feasibility studies in 1978 and 1979.
A "new policy" was issued afterwards, it was expected that the decision to build a nuclear power plant will be considered after the completion of the 30 MW, Multipurpose Research Reactor in Serpong, about 25 km from Jakarta.

BATAN experience in Public Information

Soon after the Institute for Atomic Energy was established in 1958, the first step being taken by this Institute was to diseminate the information on how important the new energy source, what we call atomic energy, can help to solve many problems in the field of agriculture, medicine, industry and the ever increasing demand for electric power.
There was no significant obstacle in giving the information to the public, and so far it was observed there hardly exist complain, protest, opposition, contra action or other attitude which might be construed as negative.
The people who live around the atomic energy centres feel no harm or fear and they believe that the Government who initiated the construction of atomic energy centres have already considered various aspects of nuclear safety to protect the workers as well as the general public.
The success was due the programme launched by the Institute, covering :

a. Technical information services.
b. Public information services.
c. Education programmes.
d. Laws and regulatory activities.
e. Research, development and demonstration.

Those programmes were carried out by arranging publication of bulletins, magazines, leaflets, booklets, scientific journal, articles in newspapers and popular magazines, press conferences, open house, study tours for students and professionals to BATAN's laboratories, training and upgrading courses for professionals, newspapermen and licensees, film production and performance, and also conducting routine travelling exhibitions in cooperation with the Ministry for Information.

In the early years these activities were carried out with no particular budget allocation, but since the fiscal year 1977/1978 a particular budget was allocated for public information, and programmes were planned more deliberately. Participation in national expositions became routine activities annually and at the end of 1983 BATAN established a Permanent

Exhibition Building consisting of two floors covering on area of 800 M2. This Permanenet Exhibition shows research and development activities being done at BATAN's laboratories.
The role of other government bodies and organizations in forming public opinion are very important and gives a great support to BATAN in gaining these success.

Up till now the activities as mentioned above are aimed for the promotion of peaceful application of nuclear technology in various fields except nuclear power.
After the Three Miles Island II and Chernobyl IV accidents, the waves of "public opinion" through news papers, seminars, parlementarian hearing, and so on, was focused on the question whether it is wise and safe to build nuclear power plants in Jawa.
To overcome this issue we increased the activities in giving information to all levels and groups existing in the general public.
These problems which have to be faced in the very near future are the issues of :

1. The risk of nuclear energy, namely how safe is safe.
2. Nuclear waste disposal.
3. Catastropic accidents.
4. Environment and social impact.
5. Low level radiation.
6. Access versus security.

Work Programme

The objective of BATAN Public Acceptance Programme is to convince and persuade the public concerning BATAN programmes, in particular those which relate to nuclear power generation. Considering this, the public can be divided into several strata a.o. :

1. General public.
2. Executive society
3. Young people like : students, member of youth movements etc.

4. Professionals.
5. Politician.
6. Press.

The information activities will be based on the objective and the strategy taking into consideration the public strata as such that the public will gain an objective understanding concerning nuclear power programme.

Working Programmes prior to the Decision of "Go Nuclear"

As we expect that the Government will make the decision at the end of the Fourth Five Year Development Plan, BATAN has launched and will continue to keep the general public informed concerning all aspects of our nuclear power programme and will aim to establish a perception of nuclear acceptance on the part of the executives, young people, professionals, politicians and the press.
These efforts will be done through lectures, writing papers and publication in the mass media, so that at the end of the Fourth Five Year Plan the consciousness and confidence of the public concerning nuclear power programme will increase.

Working Progamme During Construction

With the assumption that the Government has made a decision, the working programme during construction will consist of more intensive activities as performed during the first stage to establish public opinion in favour of nuclear energy.
Lectures will be given within a wider range of young people such as youth and students of government and private Universities, Societies of executives and professionals. Further we will also intensify to write articles for mass media and publication for students from elementary and highschools.
We expect that a good perception of our nuclear power programme within the public will have been established, so that the public will have a basic knowledge of our programme, especially the safety and reliability of a Nuclear Power Plant as a source of energy, and the executives can accept

the development of nuclear energy, especially the aspects of security, safety, reliability, economics, and the cleanness of Nuclear Power Plants.

Working Programme after Commisioning

The activities will be continued to achieve public understanding and we hope there will be no obstacle to accept the operation of NPP as an alternative energy supply which is safe, reliable and economic. The first NPP will be in operation and will be followed by other NPP's.

Decision Making in Energy Policies with Conflicting Interests

6. to 10. October 1986

Ortwin Renn

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BATAN Seminar on Nuclear Energy
Jakarta (Indonesia)

ABSTRACT

Decision analysis has frequently been criticized as an inappropriate tool for complex policy issues since it presupposes a rational and homogeneous decision maker and a consistent set of values from which preferences can be derrived and ordered according to importance. A typical policy situation is characterized, however, by a heterogeneous group of decision makers mainly interested in the justification of a preformulated policy vis-a-vis competing interest groups and by conflicting values and objectives. Therefore, a modification of the original decision analytic approach will be presented focussing on plural value inputs and participatory weighting procedures.

The approach was tested in a large policy study on future energy strategies. The study contains three major components: in a first step values and criteria were elicited by interviewing the leading representatives of nine stakeholder groups in the Federal Republic of Germany and structured in the form of a joint value tree. Second, the revealed criteria were translated into indicators. Four different energy scenarios were evaluated with respect to each indicator making use of physical measurement, literature review and expert surveys. Third, the weights for each indicator were elicited by interviewing randomly chosen citizens. Those citizens were informed about the scenarios and their impacts prior to the weighting process in a four day seminar. The results of the study were reported to the policy making bodies and served as a discussion outline to form a viable compromise for future energy politics.The chances, prospects and limitations of the applied model are discussed during the presentation and some guidelines are developed for an effective and implementable policy consultation.

INTRODUCTION

After the accident in Tschernobyl policy making and implementation of energy decisions have become more difficult than ever. On one hand side the public reacts with fear and opposition to a possible extention of nuclear power, on the other hand the economic prosperity of a country depends on an inexpensive and non-exaustive energy source like nuclear energy. Energy planning is necessarely associated with conflicting values. This situation is true for industrialized and developing countries alike. What can policy analysts do in order to resove the conflict and initiate a rational and a publically acceptable energy program?

The following paper desribes a concept of energy planning developed by a study group of the Nuclear Research Centre in Julich (FRG). The concept is based on the idea that in a pluralistic society different social groups should participate in the policy formulation process and that the values of the public should be incorporated in the weighting process to make choices between given options. As reference theory we use the basic framework of decision analysis.

The essential guideline of decision analysis is to lay out the decision options, assess the often probabilistic consequences of each option and select the one option that offers the highest expected value.This may not be of strategic interest to public decision makers. In many instances transparency of the motives for a specific decision and publicising the trade offs used in the analysis might create a political disaster, in particular if health effects are traded off against economic benefits. In addition, the policy making bodies form a heterogeneous group of individuals with different personal values, aspirations and perceptions of the institutional tasks that they are obliged to perform. The specific goals of a proposed policy might be obscure or controversial and there might also be no clear distinction between means and ends.

Hence, many policy analysts have come to the conclusion that the specific tools of decision analysis only apply to situations in which individuals have to choose between personal options almost unrelated to potential consequences for third parties. As soon as preferences of decision makers with conflicting values have to be taken into account and as soon as collective goods with external effects play a major part in the analysis, the one-dimensional process prescribed by decision theory must fail according to many investigators.

Although this criticism is true with regard to a naive adoption of decision analysis into the policy sector, there is a wide range of potential modifications of the original decision analytic framework providing for multiple decision makers and conflicting values. Furthermore, the decision analytic perspective has proven to be a rewarding heuristic concept for analyzing factual policies and an - easy to cummunicate - prescriptive method to assist policy makers to determine potential options for resolving social problems.

THE BASIC STEPS OF DECISION MAKING

According to the basic axioms in decision theory any planning process consists of seven different steps:

- Commitment and specification of *needs or goals* with respect to overall values in society.

- Choice of appropriate *criteria or dimensions* which can be used as a heuristic classification to assess consequences for each option and to define violations or fullfillments of the specified goals or values.

- Transformation of criteria in measureable *indicators* to assess the consequences of various options in a most objective manner.

- Definition of *options* that are technically feasible and correspondive to the overall aim specified in the first and second step.

- Assessment of *consequences* for each option according to the preformulated indicator list (extent and probabilities).

- Assignment of *relative weights* to each indicator (or -if appropriate- subcriterion).

- Selection of an *aggregate model* to combine assessed probabilities and weights. Usually for each indicator the assessments are multiplied with the perceived probability and with the relative weight and afterwards summed up.

As long as the total range of consequential effects (from best to worse) is taken into account, as long as individual utility functions for variations in probabilities are considered and as long as independence and non-redundancy of all dimensions have been assured, the seven-step model has proved an excellent normative guideline for rational decision making. But this good record can only be applied for decision making by individuals or by homogeneous groups. As soon as different groups with different criteria and values are involved in the decision-making process, the simple model fails, because rationally derived means to summarize values or to aggregate weights between groups are not available. All attempts to construct social utility functions are either too abstract so that they are impossible to use in a concrete case or they are rather adoptive to strategic maneuvers.

A PLURALIST APPROACH TO DECISION MAKING UNDER CONFLICT

Any approach to build a model for decision making in energy planning has to face the difficulty that not only values and criteria are disputed, but also the facts, e.g. the assessments with respect to each option. Thus disagreement is expected to appear also in step 5 describing the assessment of consequences and their transformation into indicators.

When designing the research program the study group had to consider the characteristics of the political arena in which energy policies have to be formulated and implemented.

In contrast to some other political arenas the energy scene in Germany, as in many other western countries, is characterized by the following four major features:

- A lack of unanimity among the scientific experts (or those regarded as experts) about facts
- The public's lack of confidence in scientists and policy makers
- The assignment of symbolic values to nuclear energy including moral and ethical considerations regarding industrial society as a whole
- The unwillingness of the stake-holder groups to move towards a compromise

The lack of general agreement about future energy policies among experts, politicians and interest groups has led to frustrations amongst the general public and has promoted a feeling of distrust and scepticism towards official decision makers. Public media and opinion leaders have transferred the controversy to the public, forcing people into the role of arbitrators between scientific camps. Needless to say, most people feel overtaxed by this task and recommend a more cautious strategy incorporating all the critical remarks of professional scientists. Since scientists for various reasons disagree on the question of acceptability of nuclear power, a loss of credibility has occured which makes it difficult to convey trust in the regulating bodies.

This specific situation leads to the necessity to alter the steven steps of decision making in order to cope with the conflictual situation and to gain approval by the different stake-holder groups which take part in the decision-making process.

The basic framework for our analysis was conceptualized as a modified version of the traditional decision analytic approach. The study was carried out in the years 1982 to 1985 initiated by the Federal Ministry for Research and Technology. We were asked to investigate the possibilities of designing an energy policy programme which would not only satisfy the needs and requirements of an energy-seeking society, but also provide a way of resolving the related conflicts within German society. In particular the prospective outlook and the further development of nuclear energy were to be investigated, taking into account social and psychological aspects and constraints.

Since we basically followed the idea of the seven step model of decision making, we can best describe our approach by referring to this concept.

The specifications of policy goals

The controversial question in step 1 deals with the problem if the government in a pluralist society is justified to specify universal goals and needs or if all groups in society should have an equal right to come up with their own definitions what kind of basic aims a society should pursue. We decided that any political system - even the most democratic society - should base their decisions on a few mandatory criteria, namely that the physical needs of the public should be served, that the civil rights should not be violated and that social change is not prevented or hindered. In the case of energy we specified these criteria in the following way: energy systems should provide all the services that people demand today and they will probably demand in the future; energy systems should not lead to a considerable restriction of personal freedom in order to insure protection against sabotage or terrorism nor to control and enforce state laws on energy conservation; energy systems should be flexible enough to adjust to changes in the societal structure of needs and demands. These criteria were considered as meta-criteria for the energy planning process regardless if groups in the society shared this view or not.

As expected there were no objections from any of the querried groups with respect to these three yardsticks. They were later used to specify the options that were regarded feasible. Any option which did not meet one of the main criteria was excluded from the analysis.

The selection of criteria.

The choice of appropriate criteria beyond the rather abstract level of meta-criteria involves several procedures which go beyond the normal method of decision theory by asking the decision maker what matters to him. First, we had to take into account that in democratic societies many decision makers are part of the decision process and secondly, that relevant groups in society demand that their values and interests should be considered when making collectively binding judgements. Thus, the problem had to be solved in which way we could select appropriate criteria that in principle could be approved by a group of heterogenious decision makers and be accepted by major interest groups in society.

We could use intuition, analysis of current documents in the political debate, brainstorming with experts, or surveys among the public. But these methods don't meet the two relevant conditions: approval by the decision makers and acceptance by societal groups.

Thus, we selected a rather new technique referred to as value tree analysis, which was developed at the Social Science Research Centre of the University of Southern California.

The value tree analysis is an interactive, iterative and integrative method. Individuals or representatives or important societal groups are interviewed in order to determine their relevant values and concerns about the domain of investigation. The values formulated as statements about desired states, positive intentions or preferred directions with respect to possible decision options, are organized in a value tree representing the hierarchy of values of the particular group. Each group had to approve of its value tree.

In order to cover the wide spectrum of views on energy systems in the contemporary German society, ten stake-holder groups were invited for the value tree analysis. The politically most controversial organizations were probably the Power Plant Manufacturer and the Nature Conservation League. With nine of the ten groups interviews were conducted and individual value trees were constructed. The list of participating organizations is shown in Table 1.

Insert Table 1 here

The value tree represents an hierarchical structure with the general values and concerns on top, and the specific criteria and value dimensions at the bottom. Most of the groups expressed a common understanding of the basic objectives for energy systems, but differed in their comprehension of the meaning of each value.

Accordingly, the individual trees have a similar superstructure with different focus on the degree of refinement of particular branches. Without giving preference to any individual value tree, the tree structures for the German Catholic Church and for the Federation of the German Industries are illustrated in Tables 2 and 3.

Insert Tables 2 and 3 here

The nine individual trees were used as the basic elements to construct a combined value tree for all groups respectively. Such a joint tree can be understood as the representation of major concerns in a pluralist society without focusing on the differences in weighting and importance for each value item.

But the combined tree represents more than just a list of concerns mentioned during group interviews. It is an attempt to structure various, even conflicting values and criteria in a logically consistent, generally acceptable manner which is a prerequisite for the formation of a societal consensus on how to resolve the conflict about the criteria used for evaluating different energy options.

The combined value tree was generated in the following way: The main values of the overall tree were formed by clustering and contrasting the general values of the seperate trees. All other items and terms were listed according to the hierarchical level of appearance. Then, the whole set was sorted and clustered around the respective lexical content of the main values. Finally, the clusters were aggregated and rearranged hierarchically in the overall tree with the eight main criteria:

- Energy systems aspects,
- Impacts for the national economy
- Impacts on the natural environment,
- Health and safety,
- Political impacts,
- Social impacts,
- International impacts.

The criteria "energy systems aspects" and "national economic impacts" cover costs, efficiency, security of supply, and market consequences of different energy systems. The criteria "impacts on the natural environment" and "health and safety" are self-explanatory. The criteria "political impacts" and "social impacts" include consequences for the social structure, quality of life, political decision processes, democracy and its institutions, options for future generations, etc. The criterion "international impacts" includes issues of peace, distributional justice in international affairs, and options of international policy.

The combined tree contains the concerns and evaluative criteria of all participating groups. All groups were asked to approve of the overall value tree. There was a mutual agreement among all groups that they would respect the values of the other participating groups provided that their own ones were equally accepted and considered. The acknowledgement and acceptance of each other's values structure was facilitated by the procedural mechanism that each item on the tree could be weighted by zero and thus elliminated from the list. For this reason an agreement among the interviewed groups was achieved, since every group found itself represented.

It should be noted that in this step no compromise between groups was needed, as all concerns were adopted regardless if they were perceived as important or not. Therefore, the joint tree is assumed to account for all viewpoints in the German society on energy system options. Since the joint value tree consists of more than 100 different items, omly a selection of the tree may be presented in this paper. The social and political criteria of the combined value tree are reproduced in Tables 4 and 5.

Insert Tables 4 and 5 here

By using the joint value tree as criteria list we were able to meet the second condition - approval by societal groups - by definition. The political decision makers were also satisfied with the catalogue of criteria, since the main interest of politicians is to maximize public support. A criteria list which combines all the concerns of the relevant groups is the best mean to assure this objective.

The transformation of criteria into indicators.

The next step refers to the transformation of the value tree structure into an operational system of dimensions and indicators. Ideally this task should also be performed by the various groups forcing them to be more precise in what they mean by using various terms. However, because of lack of time of the representatives of each group and the difficulity of combining different operational definitions of the same term, we used our own expertise and transformed all lower level criteria into indicators which in principle should provide us with the possibility of physical measurement or at least of scaling expert ratings.

Our group catagorized the eight main criteria of the combined tree into a catalogue of nine criteria with up to ten sub-criteria each.

Although requiring simplification of clusters and aggregation of branches this process had to maintain the content and the meaning of the overall tree. It resulted in the following categories:

- Operationality of the energy system,
- Environmental impacts,
- Health and safety,
- Security of supply,
- Economic effects,
- International effects,

- Political impacts,
- Social impacts,
- Personal impacts.

The list of criteria, indicators and subindicators is illustrated in Tab. 6.

Insert Table 6 here

In the next step we selected measurement scales to assign physical or judgemental data to each indicator. In response to the complexity of the technical information and the degree of uncertainty we used different scaling levels:

- Quantitative scaling,
- Ordinal rating,
- Rank ordering,
- controversial statements (categorial measurement level)

In order to improve the readability and apprehension of the assessment all ratings were then standardized on a four scale rating scheme (from very weak to very strong).

The final set of criteria and indicators represent a comprehensive, complete, independent, meaningful and adequate list for the evaluation of energy policies. The criteria have deliberately not been weighted, and the indicators have not been aggregated according to an index construction rule. Rather the catalogue of indicators and measures should be regarded as an approximately objective list of social concerns which render the measurement of each scenario's performances with respect to these concerns.

The generation of options.

On first glance it seems odd to look for possible options in such a late stage of the decision-making process. There are two reasons for the placement of this step after the specification of the evaluative criteria.

First, options generate positive or negative associations which unconsiously shape the analysts' selection of criteria and indicators. In most cases the criteria are defined in such way that the intuitively best option will inevitably turn out to be the "winner of the decision game". Second, the set of indicators and criteria are an excellent tool to search for new options which have not been included in the discussion so far. If one knows in advance, which criteria potential options must meet, one's imagination for totally new options might be encouraged and new solution might be envisaged.

In our study we did not construct our own scenarios, but used four existing ones. In 1979, the German parliament adopted unanimously the resolution to establish the Enquete-Commission on "Future Nuclear Energy Policy". The commission consisted of seven members of parliament and eight experts representing the fields of engineering, natural and social sciences. Because of the nuclear energy controversy in Germany and the development of the fast breeder reactor the commission assembled proponents of the nuclear energy as well as opponents.

The commission designed four scenarios of future energy situations or paths into the energy future which were supposed to comprise the full range of opinions on energy systems. This fan of prospective solutions did not only express the possible future mixes of the available energy sources, but also the value orientations of the commission members.

The scenarios were constructed in such a way that different political options were operationalized in terms of consistent energy supply and demand models for the years 2000 and 2030. The four scenarios are illustrated in Fig. 1.

Insert Figure 1 here

In particular the role of nuclear energy differs among the four scenarios: Path 1 and 2 utilize this technology to a large extent, options 3 and 4 do not use nuclear energy after the year 2000. With respect to energy conservation and solar systems paths 1 and 2 provide for a moderate amount of conservational and solar technologies, options 3 and 4 concentrate on these two means of energy conversion.

The advantage of using the four energy scenarios of the German Enquete-Commission is the approval by most societal groups including pro and antinuclear activists. Both sides could find themselfes represented in the four scenarios.

Assessment of consequences according to the indicator list.

Since the effect of the consequences of various energy systems are disputed among scientists, it was not possible to employ physical measurements for all indicators. At least we were confronted with a broad range of estimations depending on the point of view that the analyst had taken in the energy debate. For many indicators, in particular those referring to social and political aspects, the status of scientific methodology does not imply a clear theoretical or empirical relationship between the implementation of any energy system and its possible outcomes. In this situation two methods of impact analysis were used:

- *Professionals were asked to give estimations* for each indicator that they felt to have expertise in. In addition they were asked to determine the range of other possible answers to the problem given a confidential interval of 95%. Those ranges were collected and later sent back to each participant again, contrasting the position of each consultant with the ranges of all the other experts. After the revision we were able to construct a probability function for each indicator summarizing the ranges given by each expert.

- We invited energy experts and trained professional in the field of impact analysis to a *delphi seminar in order to assess the rather controversial economic, social, and political consequences* of each energy option based on their best estimate of their factual knowledge.

  A group of 17 experts employed at German universities or institutes attended the two day Delphi seminar. They were selected because they had previously published articles or books on social or economic impacts of energy systems. Deliberately we looked for scientists with different educational background. Engineers, natural scientists, economists and social scientists were invited to participate. We also tried to include persons with diverging attitudes towards the four scenarios.

  The Delphi method is an iterative and integrative procedure used to arrive at a consensus on the forecast or estimate of specified future events or situations. The experts were querried in iterative rounds with feedback supplied in between concerning the group's comments and responses.

Because the assessment had to be made for future energy situations, the participants made their intuitive subjective judgements based on a rather high degree of uncertainty. But on overage the ratings turned out to be generally sufficient for evaluating the different scenarios at least on an ordinal measurement level. The results are reproduced here in detail for the political impacts (Tab. 7).

Insert Tab. 7 here

Assignment of relative weights.

Similar to the selection of criteria and indicators it seems impossible to presume that there is a unanimous consent within society about the importance of each criterion for evaluating different energy options. There is no legitimate rationale to combine different assignments of weights elicited from stake-holder groups or the general public into a single societal weight. There are in principle four different approaches to come up with a generalized weight:

- Direct negotiations among the decision makers *(unanimious vote)*
- *Selection of a few respresentatives* out of the decision making body and using their mean weights (benevolent dictator)
- Utilization of different *voting models* (ordinal pair comparison, assignment of points, majority vote of options)
- Elicitation of *weights among relevant groups* in society and transfer of the results to client oriented politicians
- Elicitation of weights among a *representative sample* of the general public and adoption of their mean value.

We tried to elicit the relative weights by organizing a survey of the general public (one man - one vote), but we used the results of our surveys only as an informational input for the legitimate decision maker. We thought it necessary that the decision maker should have a most realistic impression as how the public at present assignes trade offs between different values. Some of the disadvantages of public surveys were overcome in our study by a special survey method, called planning cell procedure.

A planning cell consists of a group of citizens who are selected by a random process and are given paid leave from their workday obligations for a limited period of time in order to work out solutions for given, soluble planning problems with the assistence of advisors on procedure.

A group of citizens actually means a small group of about 25 people who work on a predefined task in a group process. Since the citizens involved have been selected by a random procedure they are not individually concerned in the planning problems to be solved. In order to encourage them to participate they are assigned the socially highly esteemed role of a "consultant" in the public planning process. The seriousness of the planning task to be solved is also made clear by the honorarium which the citizen receives for his function as a "consultant". The limited participation period prevents the citizen from being alientated from his real social role; he only changes his perspectives for a brief period.

In our study 24 planning cells all over Germany were organized and confronted with our impact analysis of the four energy scenarios. The task of the citizen was to rate each scenario according to the main criteria, assign relative weights to each criterion and formulate a recommendation about the desired future energy policiy.

Again it should be emphasized that all the results of the planning cells are regarded as an input for the decision-making process, and not as a substitute for the decision. This input should be regarded as a decision aid to form and shape political judgements according to the latent and overt value structure of the concerned public. If this assumption is accepted, the planning cell might be a good instrument to collect the relevant feedback from society and to reveal the intuitive preferences and values that should be the guidline of democratic policy making.

Aggregation of weighted assessments.

We considered the aggregation as a fundamental political process which should not be confined to a mathematical formula. If the help of a decision analysist ist still demanded (and this is usually not the case), he or she should concentrate on revealing the salient dimensions that define the borderlines between the preferences for one option or the other.

May be specific political procedures can be implemented to overcome some negative impacts associated with the most promissing option. May be a recombination of options can be initiated, may be a compromise can be found by compensation or by accepting compromises in other political issues. Negotiations are so complex that it is almost impossible to press them into a procedure of rational reasoning.

The dialogue of the decision maker with the policy maker is usually referred to as sensitivity analysis. By changing the different parameters or the different evaluations or assessments the decision maker gets a feeling which aspects exercise the strongest influence on the overall evaluation. Also he gets more aware of the uncertainties involved in any decision model. We think that it is most appropriate to combine the aggregation of the weighted assessments with the sensitivity analysis to provide a framework in which a most rational decision-making process can be initiated.

If the decision makers have a good impression of what to expect when aiming for any of the possible options, if they are sure that they have considered all relevant aspects and if they found a compromise in assigning weights to each dimension incorporating the wants and trade offs of the general public - if all this is accounted for, then the decision makers have all the necessary input to make a rational and - for the time being - non-improvable decision. There is no further need to confine the ultimate decision to a specific aggregational procedure.

RESULTS OF THE PLANNING CELL PROCEDURE.

So far we desribed the procedure and the methodology of the study. Although our emphasis for this paper is on the methodological aspect, we would like to report on some of the main results of the study. The evaluation of a new methodology in policy analysis certainly depends on the soundness, validity and reliability of the results that can be expected from its implementation. Therefore, we will present some of the outstanding results from the planning cell procedure.

The first task of the participants was to assign weights to each subcriterion and criterion, and later on to evaluate the four options according to each criterion. We assumed that the rank order of criteria is derived from personal values and should therefore not be altered by the information process; our information was meant to focus only on facts and their (controversial) interpretation. In order to test the influence of the information process, we asked the participants to make rank order of the main criteria on the first and the last day of the seminar.

Figure 2 illustrates the medians of the rank order for all eight criteria, comparing first and second measurement. Evidently all observed changes are only of minor magnitude and the sequential order remains the same.

Insert Fig. 2 here.

Looking at the priorities revealed by the weighting procedure it does not seem surprising (knowing the general beliefs) that health/safety and environmental quality form the top of the hierarchy. The general economic concerns - in particular, security of supply - are rated higher than the more specific concerns of financial and material requirements. It is interesting to note, though, that this criterion gained more importance over the four days information period, whereas the relevance of the environmental effects is rated slightly lower on the last day compared with the rating of the first day. Political, social and international aspects were regarded as less important for the evaluation of energy systems.

Figure 3 shows the results of the intuitive preference measurement with respect to the four energy scenarios. Intuitively the moderate pronuclear option 2 has gained the highest approval, followed by the most moderate non-nuclear option 3 (43 percent and 39 percent respectively).

Insert Figure 3 here.

Most of the respondents who gave first priority to option 2 or 3 assigned also the second priority to the other moderate option (either scenario 2 or 3, respectively). Thus, there is a clear indication for the preference of more moderate scenarios.

The two pronuclear options together were chosen less frequently than the two non-nuclear options. Approximately 16% of participants preferred the extreme solar and conservational scenario 4 as opposed to only 3% preferring the extreme pronuclear scenario 1. Evidently, there is a considerable group of highly motivated and convinced citizens with a strong antinuclear commitment, whereas an equally sized pronuclear fraction is missing. Also, more than 70% of the persons who preferred option 2 (moderate pronuclear) moved to the moderate non-nuclear scenario 3 when asked for the second priority. The proponents of scenario 3, however, were equally divided: 50% assigned their second priority to scenario 2, the other 50% to scenario 4.

When we take a closer look to the the perceived performance of each energy scenario according to the main evaluative criteria, scenario 3 receives the highest scores on average. Scenario 1 is almost inferior to all three alternatives, whereas scenario 4 is associated with positive scores with respect to environment and health and negative scores with regard to economy and security of supply. Scenario 2 is regarded as superior in all economic aspects compared to scenarios 1 and 4 and not significantly different from scenario 3. But with respect to environment and health the scores are considerably lower than the ones of scenario 3. Fig.4 illustrates the mean values of performance for each energy scenario.

Insert Figure 4 here

If we use the mean values of performance, the incorporation of any weighting assignment performed by any of the participants would have resulted in a calculated preference for scenario No 3 if the weighted means for each scenario were summed up in a simple linear model. But as mentioned before this was not the case. More than 40 percent of all respondents voted in favour of option 2. How can this overt contradiction between perceived performance and preference be explained?

Our study revealed four different reasons for this discrepancy:

- The weighting process was highly influenced by a common understanding of "social desirability". Most people did not dare to express a high preference for economic prosperity since this value could be interpreted as "egoistic" and "self-centered".

- Many respondents felt that options which receive rather negative scores on all three economic criteria should gain extra negative weights which should not be compensated for environmental benefits.

- Many participants did not share the presumption of the Enquete Commission that all four scenarios represent feasible energy options. They were convinced that scenario 3 might indeed be associated with the best possible outcomes, but that it would not meet the precondition of securing the energy demand for the next 50 years.

- Some respondents claimed that the politicians and opinion leaders to whom they had trust and confidence had expressed their preference for scenario No 2. Therefore they felt obliged to vote alike. This effect may be labelled "loyality vote".

So in spite of the highest score for the moderate pronuclear option 2, there is a tendency to perceive the share of nuclear energy as a burden which almost half of the respondents are ready to accept for mainly economic reasons, whereas the other half would prefer this burden to be replaced by conservation or solar systems.

This ambiguity in the perception of nuclear energy is even more visible if we look into the results of the questionnaire dealing with the future of nuclear energy. The vast majority of participants perceived nuclear power as necessary, economical, and promising, but on the other hand they expressed a strong degree of discomfort with this type of electricity generation. Most people supported the recommendation to confine the use of nuclear energy to that amount that all other energy sources together could not meet. However, almost everyone of this majority group voted against a complete shutdown of nuclear power plants. They were convinced that nuclear energy might play a major role in the future, provided the safety problems, the reprocessing and waste disposal problems, and the negative social impact (like police state methods) could be managed in a satisfactory way.

Also most people believed that in the long run nuclear energy had the potential to be the most important energy source for the Federal Republic of Germany, but the appropriate technology for this purpose was still to be developed. More than 70% of all repondents were convinced that the problem of waste disposal was not solved in a satisfactory way, but 60% agreed with the statement that nuclear power is safe and clean.

Whereas sex had no impact on the formation of nuclear attitudes, we detected quite intensive relationships between age, party preference, and the evaluation of nuclear power. The more conservative people voted in national elections, and the older they were (in particular over 40 years old), the more they preferred the pronuclear options 1 and 2. Older people and conservative voters tend to express more trust in established institutions and assign a higher degree of credibility to politicians and scientists. Younger people with less conservative background were more inclined to adopt the arguments of the antinuclear experts. They also assigned higher weights to environmental values and scored nuclear energy as more environmentally harmful compared to older or more conservative persons.

These results support the observation that nuclear energy has gained a symbolic position to represent industrial values in general. Persons who favour the industrial society are more inclined to evaluate nuclear energy in a rather positive manner; persons holding a sceptical view of the industrial society reject nuclear energy more frequently.

Those results were revealed before the Tschernobyl accident. Therefore, fears for accidental release of radioactive material were not very strong. As recent opinion polls demonstrate the German public has dramatically increased its concern for nuclear accidents. But with time passing by the preoccupation with nuclear accidents migh fade away, in particular if similar events do not occur in Germany itself or in the surrounding countries. In the past changes of attitudes because of nuclear incidents (like Three Miles Island) did not prevail over a longer period, but adjusted to the former level of attitude structure.

CONCLUSIONS

The techniques and methods presented in this paper can be considered as an aid to improve the political decision-making process. In a society with pluralist values and commitments technical and economic criteria are not sufficient for policy formulation and implementation. Potential conflicts have to be indentified in advance, and the pros and cons with respect to relevant societal groups have to be gathered and systematically classified.

The study on "decision analytic tools for resolving conflicts about energy policies" has been carried out to analyse, systematize and evaluate the interrelationship of energy systems characteristics and their societal perception. The comparison of the assessment profiles with holistic judgements of the possible future energy options can probably facilitate the process of finding desirable and acceptable solutions for the future technical development and its societal implementation. For this purpose we have enlargened the traditional decision theoretical approach to incorporate conflict resolution and pluralist value commitments.

We are not sure if our model will also work in different cultural contexts. But in cases that the decision making bodies do not form a homogenious entity and different social groups demand to be part of the decision process, there might be a good chance to implement similar procedures.

With respect to Indonesia we would recommend to use our model of value tree analysis for getting a feeling of society's needs and desires and integrating important social groups in the policy formulation process. By interviewing the leading representatives of important stake-holder groups the planning task force will receive information on what people are concerned about and what they would like the government to do. Unpleasant surprises and -sometimes avoidable- public opposition might thus be mitigated.

The transfer of the planning cell method does not seem advisable for Indonesia if the random selection process to recruit the participants is adopted. But we could think of a modified version of a planning cell in which representatives of social groups, highly educated citizens and government officials meet together to discuss the various options and evaluate them according to the concerns expressed by the stake-holder groups.

It would be worth while trying to apply the model of decision making under conflict in different nations and for different purposes. The model certainly needs further refinement and improvement. But it can be regarded as a first step towards an efficient policy tool which combines the often conflicting goals of rationality and public involvement.

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The Development of Public Opinion on Nuclear Technology in the Federal Republic of Germany

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Abstract

This contribution is a study of the development of public opinion on nuclear technology in the Federal Republic of Germany. The development of nuclear technology over a period of nearly fifty years is analyzed in close connection with its reputation in the German public. The picture sketched in these five chapters is a complex one.

While nuclear power played no major role in the energy economy well into the sixties, and the attitude of the public consequently oscillated between positive interest and an absolute lack of interest, it was increasingly found in the sixties and seventies that the detailed aspects of nuclear power as well as the entire problem of its use incorporated a considerable potential for public controversy.

It was, above all, the historic burden of the proximity to the atom bomb, which probably will never be forgotten entirely, that filled the citizen's mind with fear. The radiation emitted by radioactive substances, which cannot be perceived by the human senses, had a similar effect on this fear as had the memories of the horrors caused by the atom bombs dropped on Hiroshima and Nagasaki (1945) and the threat, which has continuously grown since, arising from nuclear armament and its excesses as practised by the superpowers.

These latent fears were activated in the sixties by social upheavals and historic events of various types (Vietnam war, the assassination of US President Kennedy) and by an increasing sensitivity towards the environment.

The mobilization of old, subconscious fears continued throughout the seventies, and persists in the eighties, as a result of a number of events. The energy crises and their consequences, the Harrisburg accident, but also the emergence of political groups (the Green movement, ecologists, organized nuclear opponents, Greenpeace, Friends of the Earth, etc.) are among the factors which, in the Federal Republic of Germany as well as in other countries, initiated a movement of skepticism and rejection of nuclear energy.

These counterproductive events, as far as nuclear energy is concerned, were paralleled by an expansion of nuclear power plants and other nuclear installations, not quite on the scale originally planned, but well up to a level which results in some 36% of the electricity produced in the public utility system in the Federal Republic of Germany being generated in nuclear power plants safely, economically, and without polluting the environment.

The attitude of the public reflects a high percentage of advocates, who feel that nuclear energy has an indispensable role to play in the energy supply also of the future. Specific groups, such as politicians, journalists and energy experts, express themselves much more unequivocally in favor of the important role of nuclear power.

In summary, it is safe to predict for the further development of nuclear energy in the Federal Republic a steady, but certainly not undisturbed, consolidation. A long period of probation will have to create broader acceptance in the public. Problems and risks, which have been with us for a long time in connection with conventional technologies, with which we may not be familiar, but which hardly affect the acceptance of those systems, still need to be learned in the coexistence with nuclear technology before the much disputed acceptance of today can consolidate and will be supported by broad majorities of public trust.

Chapter 1

The Federal Republic of Germany is among those countries whose economy is mainly based on services and industries. As far as its volumes of exports and imports are concerned, the Federal Republic of Germany occupies second place among the trading nations of the world, after the United States of America. Its most important export commodities are motor cars, chemical products, products of electrical engineering, iron and steel products, and all kinds of machines up to complete industrial installations and power plants. This makes the Federal Republic of Germany very much dependent on exports. Roughly 25 to 33% of the jobs in the country depend on exports.

There is a similarly strong dependence on imports. Thus, iron ore, non-ferrous metals, such as copper, silver and aluminium, as well as all metals used to process steel (such as nickel, molybdenum, tungsten, vanadium, chromium, manganese) must be imported from abroad practically 100%. This high degree of dependence on imports also applies to phosphates (fertilizers!), petroleum, and uranium. The only domestic resources available in the country are hard coal, lignite and, to a lesser extent, natural gas, lead, and zinc.

Fig. 1:
Figure 1 shows the interdependence of the most important data in this respect.

The close interdependence of the German national economy and the world market as described above makes this country highly sensitive to economic and political developments worldwide, motivating us to engage in a prospective, moderate policy of partnership with countries of different social and economic systems.

Already at an early point in time, the use of uranium as a quasi-domestic energy resource was recognized as a valuable, even indispensable, supplement to the utilization of fossil sources of energy (coal, oil, gas). Because of their high energy densities, uranium and other nuclear fuels offer extremely favorable conditions for stock-piling and transport. Over a period of thirty years the Federal Republic was able to develop nuclear technology into a powerful branch of industry. Government support through research programs and international cooperation as well as private initiative of industry jointly achieved a high standard of quality and safety of nuclear facilities and made considerable progress in managing all steps in the nuclear fuel cycle.

At present, twenty nuclear generating units are in operation in the Federal Republic of Germany, whose capacity of approximately 17,000 MWe covers some 36% of the public electricity supply, requiring only 11% of primary energy consumption.

Figures 2 and 3 present an overview of the percentage fractions held by various energy resources in the supplies of primary energy and electricity.

Six other nuclear generating units are under construction; applications have been filed for the first partial construction permits of another eight units. Fuel element factories, a uranium enrichment plant, and intermediate storage facilities for spent fuel assemblies have been completed, while a commercial reprocessing plant will be built in the near future and preparations are under way for a repository for all kinds of radioactive waste. All steps taken to complete the nuclear fuel cycle are supported by intensive international cooperation under bilateral and multilateral agreements.

All told, it almost seems as if the development of nuclear technology in the Federal Republic had proceeded without any disturbance or major opposition over the past thirty years. Yet there has been,and still is, massive resistance in parts of the public, not directed at particular plants or sites, but of a more fundamental type. The political party of the "Greens," which is represented in the Federal Parliament and in some State Parliaments, for instance, advocates an uncompromising opposition against nuclear energy. As the Greens present themselves as an environmentalist party, the unbiased observer is surprised to see this negative engagement directed, of all things, against an energy producing technology which experts regard as a highly non-polluting, modern technology designed to replace fossil plants (which have a much less positive record in this respect).

In the next few chapters it will be attempted to examine this apparent dilemma between highly advanced nuclear technology and a highly advanced opposition to nuclear power. It is probably useful to trace the development of public opinion about nuclear power in the Federal Republic of Germany in a quasi-historic study, considering also international developments over the past few decades.

Chapter 2: The Period Preceding the Utilization of Nuclear Power - the Thirties, Forties and Fifties

The exploitation of nuclear energy and its public acceptance has a history which, undoubtedly, also helps to explain some of the difficulties associated with that acceptance.

Scientific findings and discoveries in the fields of atomic physics, nuclear physics and radiochemistry made by German research workers over the past 100 years have made important contributions towards the exploitation of nuclear power in today's technology. One of the most important discoveries is considered to be the first detection of nuclear fission by Otto Hahn and Fritz Strassmann in December 1938 at the laboratories of the Kaiser Wilhelm Society (now the Max Planck Society) in Berlin-Dahlem. That discovery was explained theoretically by Lise Meitner and her nephew, Otto Robert Frisch.

This discovery of nuclear fission was to have unforeseen consequences in the following years and decades. Soon after the discovery, "...... at this historic moment,.... the work of Strassmann und Hahn..... had triggered a chain reaction of ideas and experiments.....," as a monograph on the history of nuclear fission very aptly finds (Jost Herbig: "Kettenreaktion - das Drama der Atomphysiker").

The "chain reaction of ideas and experiments" was propagated especially in the USA and in France. The letter written by Albert Einstein to the then President of the USA, Franklin D. Roosevelt, in October 1939, in which the famous scientist suggested to investigate the military uses of nuclear fission, marked the beginning of the military application, i.e., the design of the "atom bomb," long before the peaceful uses of nuclear fission.

The discovery of nuclear fission and, especially, its theoretical and practical consequences remained unknown to the public worldwide, even to most scientists. In the USA, a highly secret project was soon started under the name of "Manhattan Engineering District," whose purpose was the design and fabrication of nuclear weapons. As late as in August 1945, three months after the unconditional surrender of the German Reich (Hitler), atom bombs were dropped on Japanese cities: a uranium-235 bomb of 13 kt (relative to the explosive force of the conventional explosive, trinitro-toluene, TNT), was dropped on Hiroshima, and a plutonium-239 bomb of 21 kt (of TNT) was dropped on Nagasaki. These two nuclear explosives killed several hundreds of thousands of people immediately and several hundreds of thousands more as a result of the late effects of mechanical, thermal and radiological injuries. The two bombs were the strongest weapons ever developed by man. They ended the war between the USA and Japan, but simultaneously initiated an era of human fear of anything "nuclear," "radioactive," and "radiating," which ever since has accompanied the history of mankind like a shadow. This shadow cast on human history by that "zero hour" again and again detracts from the glamour of a modern energy producing technology with which so many hopes are associated.

The technical advancement of nuclear weapons, combined with far-ranging carrier systems (intercontinental missiles), to incomparably higher explosive forces, longer ranges and greater precision did not help in forgetting the terrors of Hiroshima and Nagasaki. Nuclear weapons based on nuclear fission and nuclear fusion ("the hydrogen bomb," thermonuclear weapons), their tests in the atmosphere and the resultant contamination of the earth's atmosphere with fission products and activation products - all this has remained a subject of worldwide apprehension to this day. Even if the nuclear superpowers USA and USSR in 1963 stopped their bomb tests in the atmosphere in favor of underground tests, nuclear armament and the nuclear arms race have remained a topical problem of mankind, a sword of Damocles hanging over all our heads. According to the annual publications by the Stockholm International Peace Research Institute (SIPRI), some 14 GT (of TNT), which is 14 billion tons of TNT equivalent, are at present kept in the arsenals of the nuclear powers in the form of nuclear weapons of various types, explosive forces and ranges. For today's mankind of about 5 billion people this means some 2.8 tons of TNT per person. There are very few figures which could better demonstrate the irrationality of weapons development. It is understandable that a worldwide protest against this development, above all by the young generation, arose rather early, in the fifties, which later was to motivate and support also the rejection of the peaceful uses of nuclear energy.

It should be recalled at this point that nuclear armament up to an overkill capacity not only resulted in a permanent sense of fear in the minds of the peoples of the world, but also established a "balance of terror" between the nuclear powers in the West and in the East. That there have been numerous, dreadful wars since Hiroshima, but not another world war, especially no war waged with nuclear weapons, is also very much a consequence of this balance of terror.

After Germany had lost the war it had started under the Hitler regime, and in which it had committed the most terrible crimes against mankind, the destroyed country had been divided in many ways. There are still two German states and a city of Berlin separated in two parts, the eastern parts of which are integrated into the Warsaw Pact and into the Council of Mutual Economic Assistance (CMEA), while the western part is integrated into the European Community and NATO. In the forties, the Germans in west and east had to struggle against hunger, diseases and suffering, had to integrate millions of refugees from their lost regions in the east, had to pay reparations to the victorious powers and had to try to reconstruct what had been destroyed. Among all those existential problems, nuclear armament and its progress was just one out of many negative perspectives of world policy, by no means a national point of concern. Even after the monetary reform (1948), after the gradual economic recovery beginning in the Federal Republic with the generous support by the USA in a number of aid programs (Marshall Plan) and gradually speeding up (German economic miracle), nuclear power was not a subject of public interest, all the more so as all scientific and technical activities in the nuclear field had been inaccessible, "verboten," to the Germans since their unconditional surrender (May 8, 1945).

The situation changed fundamentally in 1955, when the Federal Republic regained its national sovereignty in the Paris Agreements and thus also was enabled to start research and development work in the nuclear field in a situation in which countries such as the USA, the United Kingdom, the Soviet Union, and France seemed to have acquired an irrecoverable lead in nuclear technology merely because of their military engagement.

1955 also was the year of the first Geneva Conference converting into political reality the slogan of US President Eisenhower in 1953: "Atoms for Peace." The Federal Republic of Germany found itself among the nations able to participate in the broad dissemination of know-how from the USA.

Science, industry and politics in the Federal Republic welcomed this opportunity for transfer of knowledge and technology and devoted much attention to it. Only two months after the Geneva Conference, the German Federal Ministry for Atomic Matters was established in Bonn.

Already in the Paris Treaties the Federal Republic of Germany had expressly renounced the fabrication of nuclear weapons and any military research and development work in the nuclear field. Important tendencies underlying this deliberate embarkation on a new technology were the strict political will to use nuclear power only for peaceful purposes, the intention to recover the lead other nations had gained in the field, if at all possible, and finally also the technical and industrial associations of the young nuclear program.

When observed from today's perspective, more than thirty years after the beginning of nuclear research and nuclear technology in this country, the start appears to be surprisingly broad in its approach, characterized by farsighted judiciousness in tackling the manifold problems and also by a spirit of optimism hardly understandable in the present frame of mind of our society, now that nearly 36% of the public electricity supply comes from nuclear power plants. Undoubtedly, the pioneering spirit at that time was moved by the need to reconstruct the country, which had been divided and destroyed after the devastating world war, to consolidate the young democracy and, with the help of the victorious powers, of which the Western powers had now become allies and partners, use for reconstruction every modern technology available.

Certainly the nuclear flash of the bombs over Hiroshima and Nagasaki had also shocked the people in Germany, and undoubtedly also the Germans were biased against, and fearful of, anything associated with such concepts as atom, radiation or radioactive against this background of a shock experienced by mankind in Hiroshima and Nagasaki. And yet, the onset of nuclear research and technology at that time meant a step forward into the future to most people in Germany. It was a step on the way into the community of peoples and their scientific and technical cooperation and, last but not least, a clear confirmation of being recognized and accepted again among the civilized countries.

In the early days there were differences of opinion about the site to be selected for the first state operated nuclear research center to be founded. In any case, the state had to, and wanted to, exercise its duties and powers of supervision and control in the field of nuclear research and development. In addition, the site of a nuclear research center was to be found in favorable geographic location with respect to traffic connections, the proximity to universities, and the close association with large industries in the Federal Republic , for the national research centers to be founded were to act as links between the government, industry and universities. Atomic programs (as, later on, energy and environmental programs), research, teaching and industrial projects in this way were to constitute a closely knit unit.

In the choice among a number of sites, the best solution was found in establishing more than one research center. In 1956 alone, the Jülich Nuclear Research Center (near Aachen), the Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt, GKSS (near Hamburg), and the Karlsruhe Nuclear Research Center (near Karlsruhe) were founded. More centers devoted to nuclear research and other areas of big science research were created later; today Germany has 13 such national research institutions.

Already in the fifties, the first power reactor projects were drafted within the framework of the first Atomic Power Program (500 Megawatt Program), and the first research reactors were designed and built as entirely German efforts. Thus, the Research Reactor II ("FR 2") was the first project of this kind designed and completed in the country, giving rise to the expansion and also to the scientific goals of the Karlsruhe Nuclear Research Center. This reactor constituted the geographic center of the site and acted as a nucleus of crystallization in the activities pursued in the following years and decades.

Plans and objectives were established on a broad basis at the beginning of nuclear research and nuclear technology in the Federal Republic of Germany, and the whole effort was supported and accompanied by international partnership; for instance, the International Atomic Energy Agency (IAEA) was founded in Vienna, and EURATOM, the European Atomic Energy Community, was founded in Brussels in the fifties. Important structures of the nuclear fuel cycle, including the back-end steps, such as reprocessing, the investigation of plutonium and of the breeding process, already took shape in projects at that time.

In those days, there was no "nuclear controversy" in the general public, no profound obstruction of the acceptance of nuclear installations of the kind which, in the past fifteen years, has created unrest and concern also in the minds of the politicians in the Federal Republic. The reason probably was that nuclear facilities were just in the process of being built; most people had never seen them, let alone knew anything about them. Still, in the vicinity of the emerging Karlsruhe Nuclear Research Center there were farmers cultivating tobacco, corn and asparagus who expressed their fear that radioactive substances could harm their corps or at least make them unmarketable; this concern was soon dissipated in the following years. However, the shock mankind had suffered as a consequence of Hiroshima and Nagasaki continued to act subconsciously; anything atomic, radioactive or radiating was stigmatized and, in the long run and by devious ways, was to teach people to know fear.

Chapter 3: Nuclear Research and Nuclear Technology in the Startup Phase - the Sixties, the Founding Years

In the sixties, plans and preparations were continued. The second German Atomic Program consolidated and continued earlier decisions. Gradually it became apparent that the light water reactor line would be the most important commercial reactor line for the decades to come. Fast breeders and high temperature reactors were defined as the two promising advanced reactor lines and included in the project design phase. The development of ship propulsion reactors, plans for a reprocessing plant of 34 t/a (WAK Karlsruhe) and the conversion of a former salt mine into a repository for low level and intermediate level wastes raised nuclear technology to a higher level of development.

Already in the late sixties, the first two LWR nuclear power plants of 600 MWe were built in the Federal Republic of Germany: Würgassen and Stade; construction of the then largest nuclear generating unit of the world was begun: Biblis A with some 1200 MWe. A German reactor building company was established: Kraftwerk Union, then a subsidiary of Siemens and AEG, now a wholly owned subsidiary of Siemens. The third Atomic Program (1967), which was adopted roughly one decade after the start, already indicated that the lead other countries had had in the nuclear field had almost been recovered, perhaps less so quantitatively than qualitatively. Other advances, such as the construction of uranium enrichment plants, the erection of one prototype facility each of a thorium high temperature reactor and a fast breeder (or its forerunner), and the first signs of success in export negotiations with the Netherlands, Switzerland and Argentina added to the success achieved by German research and development in the nuclear field. The increase in personnel of the Nuclear Research Center from 120 (1956) to some 3000 (1966) is an indicator also of the whole national development.

This development, which almost went on like a crash procedure in some areas and was additionallly accelerated by the pioneering spirit of its founding fathers, also had a few negative sides to it:

- The transfer of knowledge and know-how took place in very close cooperation with the Western leading countries in the nuclear field, especially the United Kingdom and the United States, which means that it was organized mostly in English. Numerous technical terms were, and remained, English technical terms. This jargon was largely unintelligible to many members of the public who wanted to learn about this new technology in which they were interested. Only very much later, after more than ten years of intensive efforts spent especially by the technical committees of the German Standards Committee (DNA), the most important technical terms were harmonized, standardized and translated into German. Nevertheless, terms such as cladding, containment, pellet and others continued to exist untranslated for a long time.

- The optimism of the early years, further boosted by research and development results which compared well internationally and soon made the German "apprentices" equal partners in the nuclear business, also spilt over into the evaluation of the results to be expected. For the following decades the electricity generating costs of the fast breeder were already calculated down to minor differences in the second digit after the comma, i.e., the costs of a system whose technical breakthrough was at least one decade ahead and whose fuel cycle problems were still objects of research and development.

- This optimism made scientists and engineers overlook the need to explain to an interested public (was it in fact interested?) what the potential risks and disadvantages of this young technology might be. There was a national goal to be pursued, and a goal worthwhile concentrating on. This work, in turn,was part of an immense effort of rebuilding a country which had been destroyed in a war, divided, and whose historic conception of itself had suffered. The optimism of German nuclear scientists was also a part of a worldwide optimism which believed that nuclear power would work wonders for the world of tommorrow, such as irrigating deserts, finding food for the hungry, and developing fundamental solutions to all problems of energy supply.

This wave of optimism, which carried science and technology, was soon intermingled with a dangerous streak of pessimistic moods not yet felt by most contemporaries, but clearly discernible from today's historic vantage point. In the late fifties and early sixties, a worldwide front of protest was raised against nuclear armament, a movement carried mainly by young people, but also by scientists of all disciplines. A manifest had been publicized in the Federal Republic of Germany by Göttingen scientists, and it had been signed also by the founding fathers of the Karlsruhe Nuclear Research Center. After two terrible world wars waged and lost by their grandfathers and fathers, the sons did not want to suffer another war for themselves and their descendants, let alone a war employing nuclear weapons, a war which might well be the last and ultimate war of mankind and whose risks nobody could fathom, not even nuclear scientists. Each year, the Easter holidays saw protest rallies, demonstrations, lists with signatures and appeals against the "nuclear danger," the much dreaded nuclear armament of the superpowers soon to become reality. The protests were heard and shared by many people, but they missed their actual target, namely the superpowers and their armament plans. Despite, or just because of, their futile nature, protests of this quality and intensity kept up their own momentum; they soon concentrated on a different nuclear target chosen as a sort of stand-in, namely the peaceful uses of nuclear energy then under development.

This logical inconsistency, namely "to hit the bag and mean the donkey," as the German saying goes, may look surprising, but it is not as strange as it may appear at first sight. There were sound reasons for this apparently illogical conversion of a protest against atom bombs into a protest against "atomic technology." Historically speaking, the peaceful uses of atomic energy remained a spinoff of the development of atom bombs; the "good atomic reactor" was overshadowed by the "bad atom bomb." Most adolescents and most adults had not been told anything about reactor lines, reactor designs and reactor operation either at school or in their professional education. Not even the university courses to be attended by a student of science included nuclear physics or nuclear technology as compulsory subjects. How then was the average man on the street to assess whether a nuclear reactor was nothing but a bomblike machinery tamed with great difficulties, but still incalculable?

The United States had a lead of about two decades in nuclear technology. This lead in development also included the period of bomb deelopment and the pioneering years of reactor technology, plutonium technology and reprocessing technology. There were accidents and incidents, but only surprisingly few of them had serious consequences, such as casualties or persons severely injured by radiation. This is true in particular if one compares the susceptibility and sensitivity to failure of the budding nuclear technology with technologies used for many decades, which we think are sufficiently safe, but which are not really. In a country of "unlimited possibilities" (also in the field of journalism), such as the United States, there were also scientists and journalists, action groups and pressure groups, who turned their attention to such accidents, processed and published them in a very effective way in the media. Parallels were drawn between the effects of nuclear power plants and those of atom bombs, and discussions went on about the effects of small and minute radiation doses on human organism. The period of sombre diagnoses and doomsday forecasts began. The swelling tide of publications of this type was accompanied by films, which are still shown quite frequently in our movie theaters and also on TV, demonstrating the much dreaded late effects of ionizing radiation on plants, animals and persons in horror pictures of killer spiders several meters high, semihuman or superhuman monsters of the Dr. Frankenstein type, or terrible homunculi.

At the same time, a scientific controversy arose over some publications by Dr. Sternglass, a US radiologist who said he had detected radiation damage in the form of increased infant mortality and higher rates of death from cancer in the environment of nuclear installations.

Scientists like Gofman, Tamplin and Alfvén (the latter in Sweden) took up some of the aspects included in Sternglass' hypotheses and found and discussed new ones. In short: scientists, of all people, soon got into a heated argument about the environmental impacts of nuclear facilities, which was bound to extend to the non-scientific layman and make him feel uneasy. Moreover, where was the layman who could say he was able to decide which of the scientists were right in this argument?

Arguments among scientists: Sternglass, Gofman, Tamplin and the other "nuclear critics" did not remain uncontested. Independent scientists, also state authorities and research centers intervened, disproving Sternglass and the other "critics" in careful "countercritical" analyses (Fig. 4). In the same way in which fashion trends, toys and sports activities had been transmitted from the US to the Federal Republic of Germany and the other countries of Western Europe with some delay, the Sternglass controversy also struck Europe in the early seventies; some countries were affected very little or not at all, others, such as the Federal Republic of Germany, felt the impact clearly and for a long time.

The "threatened environment" was a subject assuming more and more weight in the public debate in the sixties, for instance in the book by Rachel Carson, "Silent Spring," which dealt with the damage arising from the use of DDT and other herbicides and insecticides. From the present point of view it is almost tragic to consider that, after the ban on DDT as a consequence of these warnings, the death rate due to malaria in many tropical countries of the earth (which had been reduced to very low levels thanks to the use of DDT) soon returned to appallingly high levels within a few years. One of those countries is Sri Lanka (Ceylon).

The two topics, "nuclear power and its hazards" and "threats to the environment," were combined in one "super-subject" engulfing large groups of the public, the intellectuals included, bringing forth a wealth of primary and secondary literature, leading to the formation of pressure groups (Sierra Club, Friends of the Earth in the USA, and parallel and successor institutions in all countries of Europe), and influencing public discussion up to political decisions, and wrong decisions, for more than a decade.

Another development, the origins of which have not been clearly analyzed to this day, determined public attitude to nuclear energy and other areas of life, both in the USA and in many European countries. This development can only be sketched very roughly in this paper.

The assassination of US President Kennedy in 1963 acted like a shock on many people to whom this President had been a symbol of hope, a charismatic figure. The United States, the leading Western power in the conventional and the nuclear sectors, guarantor of democratic liberties not only within the boundaries of the USA, but for all countries in Western Europe, had set a clear limit to Communist expansion in the deliberate action Kennedy had taken against Cuba and the Soviet Union. This young President had been shot before his political career had reached its peak. His successor, Lyndon Johnson, seemed to belong to an entirely different generation, to be a different personality; he was a President without any charisma. Was it the destruction of the hopes that had been put in John F. Kennedy, or was it the lack of political farsightedness of his successor, Johnson, which got the United States deeper and deeper, finally irretrievably, into a war to end only after many years and with great sacrifices by the USA in Vietnam? The reputation of the US in the free countries of the world had suffered tremendous damage, most of all in the States proper and, of course, also in those countries which had recognized the US as the bulwark of democracy, good will and freedom.

It is not certain whether the student revolts beginning in the sixties in the USA, in France, in the Federal Republic and in other countries were indeed caused by this "Kennedy/Vietnam effect" of shattered hopes and expectations. At any rate, these historical events greatly contributed to developments in society in the years to follow. For the Federal Republic of Germany it can also be said that twenty or more years had passed since the end of World War II, reconstruction had been completed more or less, postwar destruction and poverty had given way to material wealth, and a new generation was growing up whose members had not been directly affected by the horrors of war. This new generation grew up in a society it found "saturated" and "materialistic," a society in need of new impulses, of shedding old educational structures and of finding new concepts of authority and of the freedoms guaranteed in the constitution.

These revolutionary movements, which sprang up everywhere, were directed against traditional authorities and institutions, also against the ethical principles represented by the traditional leading power, USA, whose unfortunate role in Vietnam was critized severely; they also reinforced leftwing and ultra-leftwing political currents which, in those years, felt that their time had come and, for this reason, did not reamin passive.

Without the public realizing it, the period of maturation of nuclear technology and reactor technology was paralleled by the growth of a protest potential able to unfold its activities in the next decade, the seventies. The anti-authoritarian wave, the permissivity in thought and action spreading in the sixties in families, schools and partnership relations - all this was supported and encouraged in many statements by leading politicians calling for "more democracy," for the cooperation of the public in political decisions, and for creative self-realization.

Chapter 4: The Breakthrough of Nuclear Technology - the Seventies: Euphoria, Crises, and Resistance

There are no precise time limits in the developments described in the chapters above. A classification by decades is arbitrary and only arranges the subject matter for historical purposes. This means that many of the events described here as being part of the seventies can be found to have been present already in the sixties. For instance, a pamphlet published by a major German publishing house in 1968 ("Eight Arguments against Nuclear Power," Verlag Handelsblatt) already contains the topics of discussion which influenced the broad public and political debates in the Federal Republic of Germany in the seventies and eighties, including the question about the disposal of radioactive wastes, economics, lifetime, and sufficient safety of nuclear power plants. As viewed from the vantage point of today (1986), the public debate about some aspects of the nuclear power problem looks like a sequence of focal subjects. Today it can be said that some of those subjects have their "comebacks" and become topical again. (See also Fig. 5).

The seventies saw the economic breakthrough of the light water reactor (LWR) in its two variants, the boiling water reactor (BWR) and the pressurized water reactor (PWR); this phenomenon was experienced worldwide and, especially so, in the Federal Republic of Germany. In this country, three so-called demonstration reactors, two BWR and one PWR, symbolized this breakthrough, as explained in the previous chapter. They were followed by nuclear power plants in the 600 MWe, 800 MWe, and the 1200 - 1300 Mwe categories. The latter, largest, unit size soon established a sort of standard which, although it could in principle be surpassed, led to a consistent unit size of LWR power plants because of the optimization achieved as a result of cost degression.

Biblis A with 1147 net MWe, commissioned in 1974, and Biblis B with 1238 net MWe, commissioned in 1976, became the protagonists of a type of modern pressurized water reactors worldwide regarded as safe and economic. This international recognition led to many contracts from Germany and abroad, to the nuclear agreement with Brazil in 1975, and to the contracts concluded by Persia (Iran) a little later. The two contracts today appear to be symbols both of the euphoria and of the setbacks soon to occur.

Already in the early seventies, construction was begun of the THTR 300 near Uentrop-Schmehausen, the first prototype high temperature reactor, and of the SNR 300 near Kalkar, the first prototype fast breeder reactor, both plants designed for an electric power of 300 megawatts. In 1972 the prototype reprocessing plant, WAK, went on stream in Karlsruhe. In 1974, close cooperation between Germany and France began in the research and development of advanced reactor concepts, especially the fast breeder.

In the first Energy Program adopted by a German Federal Government (1973) nuclear energy had been assigned an important, even indispensable, role in the energy supply plan; in line with the increase in energy consumption predicted at that time, the program assumed that an aggregate nuclear capacity of 45,000 to 55,000 MWe would be required for 1985. The nuclear power plants in operation and under construction in 1972 had an aggregate power of just 7200 MWe.

Again, a coincidence in time can be found for optimistic, even euphoric, aspects of nuclear development and very pessimistic and counterproductive developments. The expansion of nuclear power almost on schedule seemed to be enhanced even further by the oil crisis of 1973. Oil became scarce and expensive, which meant that a policy of oil substitution had to be pursued also on a long term basis. A monopolist preference for oil, which had been so extremely cheap until then, could no longer be tolerated. Nationwide, oil absorbed more than 55% of the primary energy consumption; the national oil production was, and still ist, less than 5%. Nuclear power appeared to be predestined for this substitution, especially in electricity generation. However, also the priority given to the use of coal was emphasized: hard coal and lignite are the only sources of energy available in large quantities in the Federal Republic.

Almost simultaneously with the oil (price) crisis, the Federal Republic was hit by an environmental crisis, another late effect imported from the USA: environmental problems assumed an increasingly larger proportion of the public debate. Rachel Carson's book was widely read, the publication by Meadows and Meadows, "Limits to Growth," and the follow-on publication commissioned by the Club of Rome reached many people and were in line with the "spirit of the time." Although many of those ideas and computerized forecasts later were found to be unsatisfactory and biased, many people regarded them for what they were: warnings expressed to the decision makers of this world.

Even if the reconstruction of a country devastated by war had become almost a thing of the past, regarded as nothing more than a topic for history lessons by the younger part of the population, the fifteen to twenty postwar years of environmental unconcern were over once and for all. The symbol of the "smoking chimneys," an expression denoting economic recovery in the fifties, now became a phrase expressing environmental concern and profound doubt in economic growth, wealth and the use of energy, which was considered to be wasteful in general. Nuclear power automatically became one of the targets of this intellectual and ecological doubt. To many people, nuclear power even seemed to be the very protagonist of this wasteful use of energy, for it promised low electricity generating costs and, with its large nuclear generating units and huge cooling towers, had become highly visible to many people on many sites and begun to replace other techniques of energy generation. It was no longer the small research reactor or power reactor, then regarded as a symbol of technical progress and a national achievement, but the 1300 MW unit with its high cooling towers (160 m) visible from afar which was regarded as a symbol of an unknown future felt by many to be threatening when people started talking about nuclear reactors. Old fears associated with Hiroshima were revived. Concern about the future, the unpolluted environment, personal wealth, the employment situation, the end of the worldwide economic crisis - all this added increasingly more somber touches to the picture.

In the late sixties and early seventies, "public action committees" were founded in many places in the Federal Republic, smaller or larger groups of concerned citizens working for common goals, such as streets on which children could play, children's playgrounds, more green areas in the cities, against the construction of highways, for noise control measures, against the spreading of cities into the open country......and also against building nuclear power plants. Especially the opposition to the construction of nuclear power plants and other nuclear facilities acted as a nucleus of crystallization. The Energy Program of the Federal Government quoted above had forecast an expansion of nuclear power plants which would have meant 36 new nuclear generating units within only twelve years, that is, three new units per year. The public understandably viewed these plans with misgivings, even fear, especially in a situation when concern about a threatened environment and about increasingly scarcer and more expensive energy resources reinforced such fears.

The planned construction of one specific nuclear power plant (Kernkraftwerk Süd in the southwestern part of Baden) concentrated, institutionalized and multiplied as well as popularized the actions of such public action groups against nuclear power in a way not experienced before.

The public utility company responsible for that region had defined a site in the city of Breisach, southwest of a region of great scenic beauty, with a unique flora and fauna (the Kaiserstuhl hill) and, in addition, one of the most famous wine growing regions in Germany. The protests by the public action groups were directed against the anticipated radiological and meteorological impacts of the planned nuclear power plant. Especially the adverse effects expected to arise to the conditions for growing wine greatly excited the minds, and many people had mental pictures of the sunny slopes of the Kaiserstuhl hill threatened by misty, humid vapors rolling up from the River Rhine. This was intolerable and produced loud protests in broad groups of the public.

In the public inquiry prescribed by law for hearing the objections against such plans, the licensing authorities committed a number of blunders and psychological errors vis-à-vis the highly emotionalized opponents. Very soon opposition turned into open hatred. The Breisach case had a number of consequences with effects extending far into the next few years and also to other sites:

(1) Different groups motivated by very different reasons solidarized. The protests by wine growers, fishermen, critically minded scientists of adjacent universities, concerned citizens and public action committees produced an explosive mixture.

(2) The opposition against nuclear power assumed international proportions: nuclear opponents from the adjacent regions of Basle, Switzerland and Alsace, France joined in the protests against the planned site.

(3) The nuclear controversy grew from a local affair into a dispute between government and opposition parties in the state and throughout the Federal Republic.

(4) The controversy between nuclear plant operators and the public developed into a legal battle which, in the years to come, went through all stages of litigation before the administrative courts about nuclear power plants existing and planned on many sites, often assuming sharp, unconciliatory forms and involving tremendous expenditures of time and documents for each project, thus causing unforeseen delays and often bringing plans close to the limits of what was financially calculable by the operators (see Figures 6, 7 and 8).

(5) The massive protests in many cases led to revolts which, by their very nature, also attracted groupings which were not really interested in the causes of the movement but liked to use the opportunity for revolution and for "overthrowing the system." Besides the

> anarchists and similar characters, which can be found in any society, these were especially Communist-Marxist parties and groupings, which saw the dawn of their desired world revolution come up. It should be added that the influence of these groupings has not decreased a bit over the past ten or fifteen years, but has been increased and reinforced by violent terrorists and has influenced developments at many demonstrations, not only those against nuclear facilities.

Breisach as a site was rejected because, under an order by the Federal Ministry of the Interior, thermal power plants at that time had to be equipped with cooling towers unless they were located close to the estuaries of large rivers and could easily be cooled directly with sufficient amounts of water the whole year through.

For the planned nuclear power station of Breisach this new condition would have meant that one or two cooling towers of 160 m height would have emitted their clouds in the main wind direction (from southwest to northeast) straight to the vineyards on the slopes of the Kaiserstuhl hill. This was not acceptable even to the licensing authority and its expert consultants. As a substitute site, an area in the valley of the Rhine River was selected some 10 km northeast of the Kaiserstuhl hill near the village of Wyhl. The distance to the nearest vineyards, perhaps 4 or 5 km, was felt to be sufficiently large, the main wind direction did not give rise to any meteorological disadvantages for most of the year. The situation appeared to be under control. And yet Wyhl became the spark that made the charge explode. Why? Probably because the controversy about Breisach had generalized resistance by a number of effects of aggregation and multiplication. Resistance had become a permanent institution, and a mobile one at that, which operated nationwide and could easily be transported to other sites, as was to be seen in the next few years. In the words of the die-hard nuclear opponents, Wyhl also meant: "No nuclear power plant here and none elsewhere." Wyhl led to Brokdorf, Grohnde, Kalkar, Gorleben, up to Wackersdorf, the site of the planned reprocessing plant of 350 t/a, which is currently a subject of violent discussion and fighting. All these places experienced demonstrations on the largest scale, some of them assembling 50,000 participants, and also a number of violent battles.

The other events important for the seventies will be briefly summarized under the following headings: dialog with the public on nuclear power; the Greens; risk studies; Harrisburg, TMI II; Gorleben/waste management problems.

The State Governments and the Federal Governments, which had basically agreed in their positive assessment of nuclear power at that time and until the early eighties, concluded from Wyhl that the controversy should not be allowed to develop into a civil war. A "dialog with the public on nuclear energy" was established in which all socially important groupings were to participate, such as the public action committees, scientists from state operated research centers and utilities, but also priests, politicians, and educational institutions. This dialog existed for a number of years; perhaps it did put some of the problems associated with nuclear power on a more rational basis, but it was unable to shift the controversy proper to a more rational track. The debate about nuclear energy had already become too emotional for that, and "third parties" (those who wanted to change the system, leftist radicals, criminals) had become too much part of the disputes. Also too many scientists and engaged laymen had acquired a personal reputation in the dialog, although most of them had no technical competency whatsoever in the matter. Yet they soon made for themselves a reputation as speakers, partners in discussions, authors and initiators; in some cases they even made money on top of that reputation and, in this devious way, enjoyed (pseudo-) scientific fame. This dialog with the public practically stopped with the change in government in 1982.

The Greens. There were numerous action groups and public action committees with hundreds of thousands of members. As a consequence of the revolts in the sixties there was an extraparliamentary opposition, also against nuclear power, about which all parties in the Federal and State Parliaments, the parliamentary opposition included, were pretty much of the same opinion. In the seventies, therefore, a new political party emerged, the Greens, which after lengthy preparations and much internal strife moved into many State Parliaments and into the Federal Parliament wherever they were able to win more than 5% of the votes (the so-called 5% clause). True, the Greens did not become a party because they were against nuclear power, but their attitude to nuclear power has been, and still is, negative. Their uncompromising "no" to nuclear power is documented, for instance, in their demand to close down all German nuclear power plants (whose safety and quality standard is regarded as the best worldwide) after the major accident in the Soviet reactor of Chernobyl had become known (April 28-29, 1986).

From the late seventies onward, the resistance to nuclear power concentrated in the parliamentary opposition by the Greens, which was quite efficient in many ways. This is true despite the fact that the seventies, with the major oil crises of 1973 and 1979, to all intents and purposes represented a veritable appeal for substituting oil, for implementing non-polluting, safe and economic nuclear power schemes. The opposition had formed and established itself, it had acquired a dynamics of its own no longer to be slowed down by technical arguments based on reason. In a party representing only a few percent of the votes this actually should not play a role, but it was seen later that the party in government until 1982 (SPD) since that time has given up its consensus with the other major parties, which had been maintained until that time, in the obvious hope to recover votes lost to the Greens; the success of this dual approach is bound to be doubtful in the long run. In this connection it is also interesting to look at the outcome of the last federal elections (Fig. 9), which indicate percentages of votes in favor of the Greens below the national average in practically all regions where nuclear facilities are operated. Proximity to a nuclear power plant, as is also apparent from a separate study (the Biblis Study), is tantamount to more knowledge about nuclear power and, hence, less sensitivity to the fear which, unfortunately, is systematically provoked by the Greens.

In 1975, the famous Rasmussen Study (WASH 1400) was published; in 1979, the German Nuclear Power Plant Risk Study appeared, which was based on the first phase of Rasmussen's publication. Both voluminous studies in a very detailed way dealt with the risks inherent in (light water) nuclear power plants of US and German designs, respectively. Although it is impossible to sum up the contents of those studies in a few sentences, it is probably safe to say this:

- Major accidents resulting in radiation damage or death to third parties, that is to say, people in the environment of the nuclear power plant, can arise only as a consequence of a grave loss-of-coolant accident leading to what is called a core meltdown.

- Accidents of this severity have extremely low probabilities. Their frequency can be compared to the frequency of rare natural disasters, such as the crash of a large meteorite on a big city, which is an accident that could happen any time, but is not seriously considered by anybody.

It should be assumed that this result did much to pacify the public debate. However, this is not really the case, and perhaps it is understandable why. The authors of the German Risk Study were aware of this potential negative effect when they wrote in the summary of their main volume:

- "Events excluded on the basis of human assessment could easily assume a real character in a detailed analysis. Potential hazards, which most probably will never lead to concrete damage and which do not play a role in the minds of most people, are thus brought to everybody's awareness. In this way, the paradoxical situation can arise that certain risks are demonstrated to be minimal, but are feared even more because of this very demonstration....."

From this more psychological than scientifically exact assessment it can also be seen how opinion makers can affect the public mood by generating and propagating fear, for instance, in order to exploit a widespread feeling of public "angst" for their own political purposes in elections. 1979 was the year not only of the German Risk Study (DRS), but also of the Harrisburg TMI-II accident and of the public inquiry about the planned construction of the 1400 t/a reprocessing plant at Gorleben, Lower Saxony, Northern Germany. The Harrisburg accident, which we have known for about one year to have been a major accident causing some 20 and more tons of fuel assemblies to melt (a finding photographed by special cameras only some six years after the event), had a very negative impact on the public. The image of what was considered to be practically an absolutely safe technology seemed to be destroyed and fear of the accident spreading further increased tremendously as a function of the number of reports published in the media (at one point in time, roughly 1000 journalists were on the spot).

In summing up the findings after the Harrisburg accident on the basis of what is known today one can say that the opponents to nuclear power were confirmed in their views just as much as the proponents were in theirs. The assertions of many opponents that the accident had increased the cancer rate and infant mortality has not been confirmed either theoretically, in the light of existing medical and radiological knowledge, or practically from the evaluation of statistics. As the notorious Dr. Sternglass also used this opportunity for his doomsday diagnoses, it was to be presumed for that very reason that nuclear power once more was to be discredited by statistical manipulations.

Nuclear power experts, especially after having learnt about the extent of the Harrisburg accident, were able to point out that the reactor had behaved in a very good natured, that is to say safe, way despite many technical failures and an accumulation of human errors.

In a nutshell then, see Fig. 10, the confidence in safety among the proponents of nuclear power suffered only slightly, while the front of the opponents clearly became stronger. This situation applies to the USA, while in the Federal Republic, despite similar criticism, the insight gained ground over the years that the German reactor safety concept was much more efficient and, consequently, there would be no German Harrisburg (let alone a German Chernobyl).

The Harrisburg accident coincided with the date of the German Gorleben hearing, a hearing comparable to the British Windscale Inquiry, dealing with the pros and cons of a planned reprocessing plant. However, what was involved in this case was more than just a reprocessing plant, but a national waste management center, designed to combine reprocessing and conditioning of radioactive waste, fuel (re-)fabrication, and intermediate and final storage of radioactive waste on one site. In the opinion of the government and of all experts, these plans constituted an optimal solution for closing the nuclear fuel cycle. That this solution was not adopted in the end was certainly due less to the intervention of the Harrisburg accident than to two decisive facts:

- At that time, six years after the publication of the Energy Program of the Federal Government, it could be foreseen that the original forecast of 45,000 or even 55,000 MWe could not be met to any degree in 1985, and that the energy crises of 1973 and 1979 and their consequences in general had clearly retarded economic and industrial developments. The concept of a national waste management center had been based on the original forecasts, being designed for 1400 tons of spent fuel assemblies per annum, which meant that it was now outdated.

- The opposition against nuclear power in the Federal Republic had assumed proportions in a number of large scale demonstrations in several places, and in the strategic resistance to a reprocessing plant in particular, which did not fail to influence even political decision makers. Although the moderator of the Gorleben hearing, Carl Friedrich von Weizsäcker (brother of the present German Federal President), a renowned philosopher and physicist, at that time stated that there had not been one argument by the "critics" (= opponents) of the planned facility which had not been convincingly disproved by the "countercritics" (= experts in favor of the facility), the Lower Saxony State Minister President decided that "the plant could not be built at the present time for political reasons." It was cold comfort to the proponents who, according to Weizsäcker, had been justified in their assessment, when the Minister President commented that a plant of this type was "basically feasible on scientific and technical grounds."

The dice had been cast against the integrated waste management center, against the optimum solution. However, closing the nuclear fuel cycle continued to be a national goal of high priority. The two fact finding committees instituted by the German Federal Parliament after 1980 to deal with the subject of a "future nuclear energy policy" discussed the waste management problem as well as the need for advanced reactor systems, especially the fast breeder; these disputes confronted "critics" and "counter-critics." In the well-known spirit of German thoroughness an attempt was made to find a workable compromise in matters of nuclear energy, and energy in general, in a group of parliamentarians and scientists. The scenarios submitted by the fact finding committees included four very different energy supply paths, the extremes of which (1 and 4) were associated with a highly advanced utilization of nuclear energy and the total abstention from nuclear energy, respectively. The recommendations resulting from the sessions the fact finding committees held over many years neither improved nor generally changed public opinion about nuclear energy; the large number of minority and majority votes by the members of the committee in many decisive questions did not really help responsible politicians in their decisions. Nevertheless, they still constitute a rich source from which each Federal Government in power can quote to substantiate its decisions. One of those decisions is the construction of a medium sized reprocessing plant as decided in a majority vote by the fact finding committee; another decision is the completion and commissioning of the SNR 300 prototype fast breeder reactor near Kalkar.

In developing the fast breeder, the Federal Republic of Germany and France were practically on an equal footing in their close scientific and technical cooperation fifteen years ago. Today France has a lead of approximately twelve years in breeder development. Consultations, litigation before administrative courts and even the Federal Constitutional Court, objections and requirements for backfitting safety measures have caused the Federal Republic to lag behind in breeder development. Also in the expansion of its nuclear generating capacity France has acquired a clear lead, thanks to a decisive energy policy, industrial policy, and interior policy. On this, see Figures 11 and 12. Also the attitude in the public vis-à-vis nuclear power obviously is positive. Even the Communist Party of France has adopted a "national" attitude relative to nuclear power, which means that it fully supports the country's nuclear policy, while the leftwing parties in the Federal Republic of Germany are almost fanatic in their opposition against nuclear power. Although it would be interesting to analyze the attitude to nuclear power found in the other European countries, this chapter shall be concluded with the above comparison between the Federal Republic and France.

Chapter 5: Nuclear Power on Its Way to Normality? The Eighties: Steps towards Consolidation

We are already beyond the first half of the eighties. Nuclear power in the Federal Republic of Germany has proved not only its environmental compatibility and reliability in supply, but also its economics. On this, see Fig. 13, which demonstrates the economic edge of nuclear power plants over hard coal fired power plants up to the lower medium load range in electricity generation. This comparison is particularly important because normally hard coal, being an abundant national resource, is favored in the energy programs for reasons of employment policy and preferred almost uncritically in daily political proclamations by practically all parties.

For environmental reasons, burning hard coal and lignite will carry tremendous financial burdens in the eighties: facilities for dust removal, desulfurization and denitrification, which will have to be fitted to fossil fired power plants, will add to the present cost edge of nuclear power. The relatively low cost percentage of uranium fuel in the electricity generating cost stabilizes an electricity economy which, for this reason, bases its operation on the indispensable role of nuclear power in the baseload range of electricity generation, thus raising uranium (and the plutonium produced from non-fissile uranium) to the rank of "quasi-domestic" energy resources.

Over the past few years, German nuclear power plants have demonstrated their high availability in terms of capacity and time also by international comparison. Three or four German nuclear generating units have long been at the top of the list of the almost 400 nuclear power plants operated worldwide, and the Grohnde Nuclear Power Station commissioned in 1984 was the world's first nuclear power plant to generate 11.48 billion kilowatthours of electricity in one year (1985).

The development of the so-called "convoy" concept, a series of identical nuclear generating units at present comprising three plants, which could reduce the time required for completing the difficult licensing procedure, i.e., ultimately the time to commissioning, from at present ten or twelve years to some six years, is another step towards more economy. Other advantages were achieved by reducing the annual downtimes required for maintenance, inspection and repair by applying more modern technical procedures. If such progressive techniques were exported it would be possible, according to German experts, to make nuclear power the more economic energy technology even in those regions in the USA where coal mined at low cost and used for electricity generation would have a positive impact on electricity generating costs.

The Federal Republic is firm in its obligation to tolerate no abuses of fissile material or of nuclear research for military purposes. This contractual condition is inspected and checked regularly and strictly by a number of international institutions, such as IAEA and EURATOM.

The installation of repositories for radioactive waste of all categories, and of intermediate storage facilities for spent fuel and radioactive waste, is either partly completed or in the process of preparation. Also construction of a reprocessing plant with a capacity of 350 t/a (Wackersdorf, Bavaria) was begun in the past few months. However, in this case it is seen that the plans of the operator (DWK) and the firm political will of the State Government concerned and of the Federal Government, which is of the same political colour, is now meeting a major obstacle in the change of mind the leading opposition government underwent for tactical reasons in the light of coming elections. The debate about Wackersdorf as the "missing link" in the closed nuclear fuel cycle has assumed proportions combining elements of a religious war with those of a more folkloristic nature. This dissent, which is at present being fought out in a lot of heated exchanges, can only be overcome by the "normative power of facts," meaning a facility built and commissioned, whose functioning capability and safety is indisputable according to the present of the art, but which can be proved to the opponents and the public only in practical operation, that is to say, roughly ten years from now. However, this is a period of time for which a lot of stamina and steadfastness of the responsible politicians is demanded, and in which perhaps also changes in the overall political situation will have to be taken into account.

Along with the plans for the reprocessing plant, planning studies were drafted on the direct repository storage of spent fuel assemblies in accordance with the decisions by the fact finding committees. The construction and commissioning of a plant for this purpose is now taking shape and will be devoted to the safe containment of such reactor fuel assemblies for which reprocessing is not, or not yet, feasible.

Now the question emerges whether these undisputed steps forward in the nuclear power field have also assured the public acceptance of this technology.

Any reply will depend on the way in which the question is worded. If one looks at the results of an opinion poll last organized on a larger-scale in 1984 one sees that the consolidation of nuclear power is reflected by the majority opinion that nuclear power should be continued at the present level, but that there is a clear decrease of the number of answers in favor of nuclear power being expanded further. The number of strict nuclear opponents may have increased slightly in the past few years, but it is a clear minority, albeit a minority which cannot be disregarded because of the unmistakable, vociferous way in which it makes its opinion heard. On this, see Fig. 14.

A closer look reveals a complicated pattern of attitudes to nuclear power and its position. Although more than two thirds of the public regard nuclear power as necessary to protect the continuity of electricity supply, a surprisingly high percentage of the public clearly underestimate the present development status of nuclear power. 30% think that the number of nuclear power plants in the Federal Republic is eight (at the time of the inquiry it was eighteen). While 68% of the public asked regarded nuclear power as a form of energy which could be expected to secure the continuity of energy supply in the future, 75% of the politicians, 83% of the journalists and almost all epxerts in energy matters asked in this poll advocated this important role of nuclear energy. The opinion frequently heard in Germany that nuclear power is a subject of debate among experts is thus disproved in a very clear way.

Contrary to the persistent stream of fear of things atomic, radioactive, radiating, contrary also to the small number of accidents and disasters, such as Harrisburg and Chernobyl (were those in fact disasters, or were they not technical accidents and incidents occurring more frequently and with much graver consequences inother sectors of technology?), nuclear power will remain an important pillar of energy supply in the Federal Republic of Germany and in more than thirty other countries of the globe. It is a technology for energy supply whose environmental compatibility, safety, economy and quality of supply becomes more and more clearly apparent. Public acceptance will probably be won only in the course of a human generation. Like success in many other fields, it will not be available for nothing.

Area:			248.692 sq.km
Resident population:			61.5 million (1985)
Population density:			247 inhabitants/sq.km
Working population:			26.1 million; unemployed: 2.3 million
Sectoral breakdown of the working population in %		/net product in %	
Agriculture and forestry	5.4	2.8	
Industry	43.7	43.5	
Services	50.9	53.7	
Gross domestic product (GDP) (1983)			1265 billion DM
Percentage share in world trade:			approx. 10 %

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Data on the Federal Republic of Germany

Energy resources	Million TCE	Percent
Oil	161.0	41.5
Hard Coal	79.0	20.4
Natural gas	60.0	15.5
Nuclear power	41.3	10.6
Lignite	36.0	9.3
Water, electricity foreign trade balance	6.0	1.5
Others	4.7	1.2

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Energy resources (primary energy FRG/85)

Nuclear power	36 %
Hard coal	28 %
Lignite	24 %
Water	5 %
Natural gas	4 %
Others (refuse, gases)	2 %
Heating oil (heavy)	1 %

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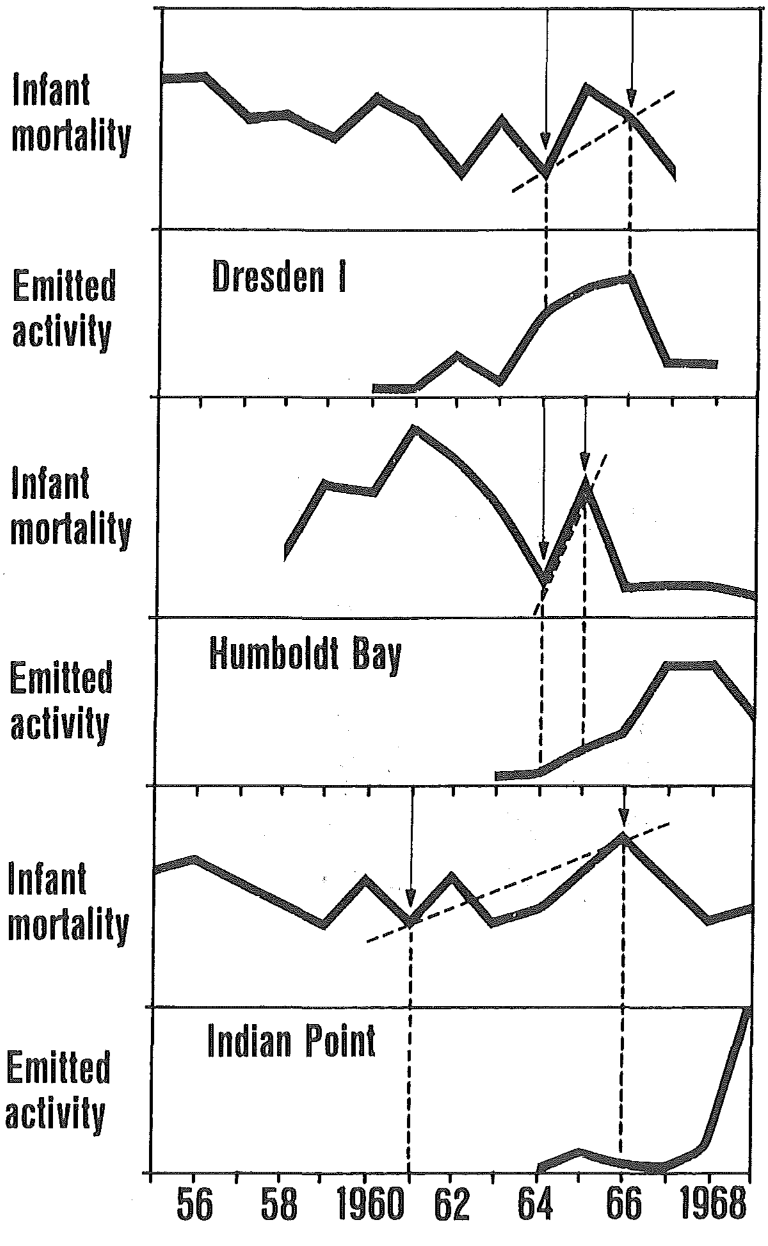
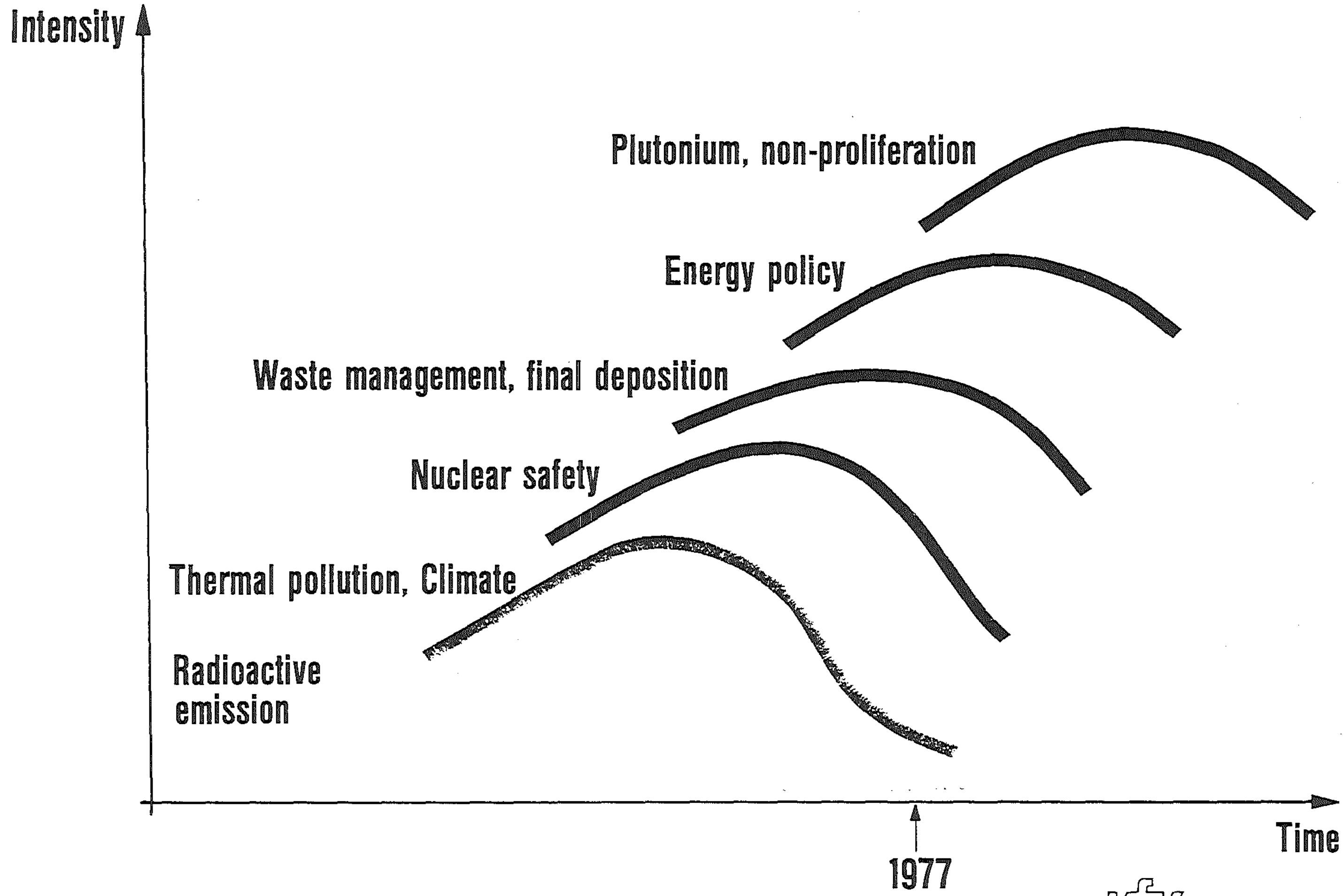
Energy resources (Public electricity supply FRG/85)

Figures selected by Sternglass

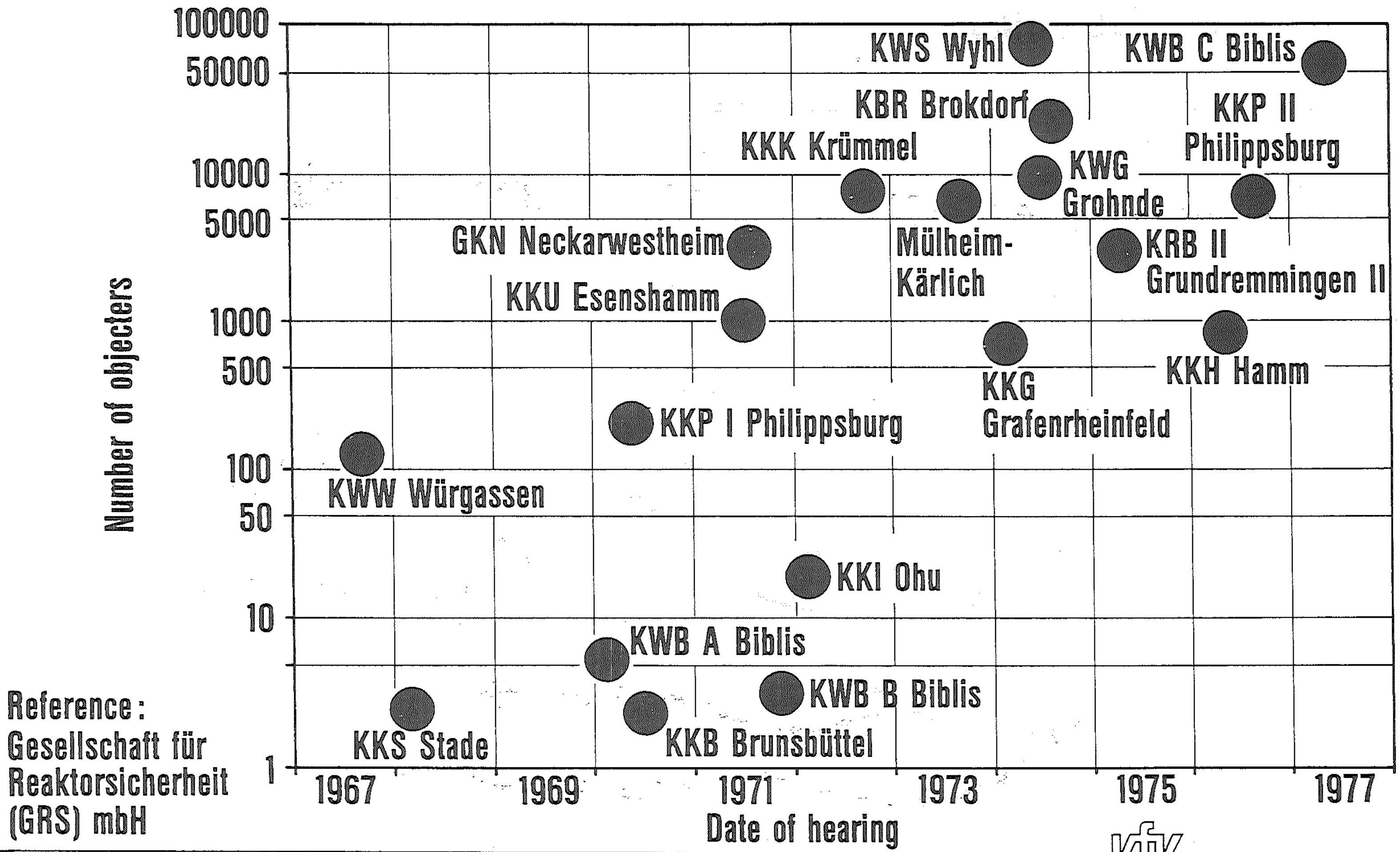


Reference:
Helmut Böck,
Naturwissen-
schaftliche
Rundschau
Nr. 27, 1974

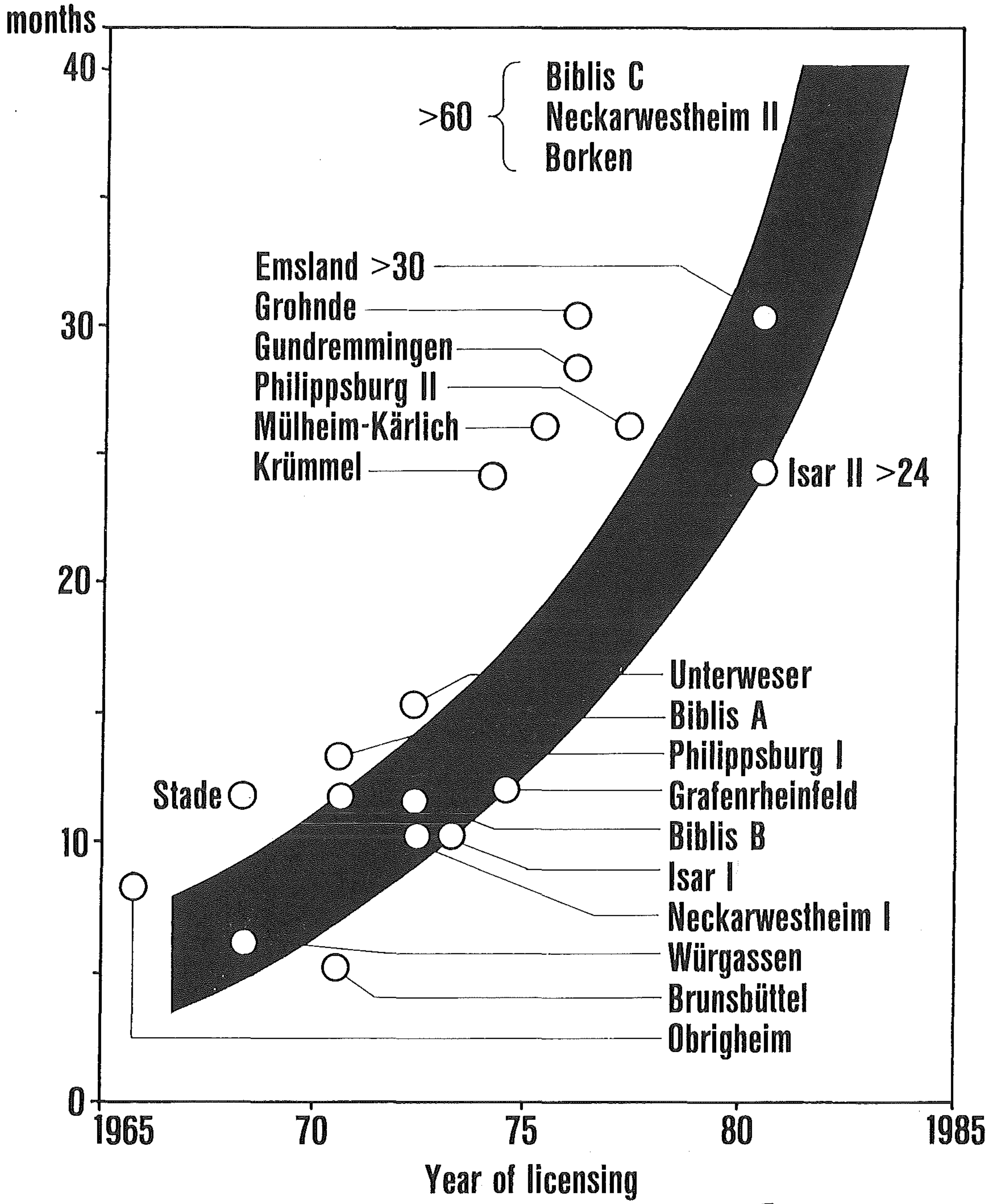
Infant mortality (Environments of nuclear power plants)?



Development of „public" nuclear power problems



Objections raised against nuclear power plants



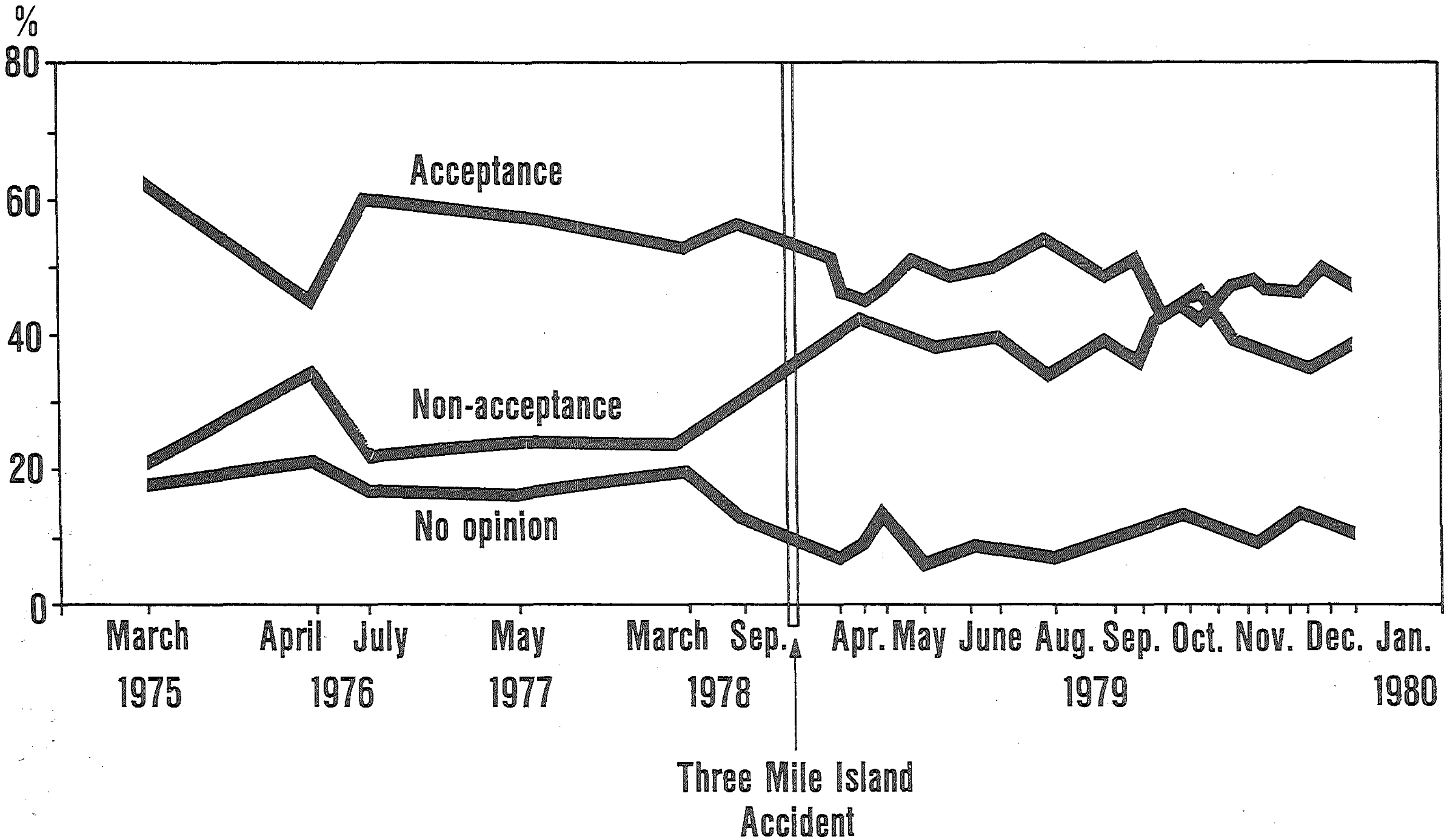
Time between filing date for permit and issuance of a first partial construction permit

Nuclear power plant	Net power	Date of 1st TEG	Planned starting date at time of contract	Date currently planned	Delay (years)
<u>Under Construction</u>					
Krümmel	1260	12/73	1978	1983	5
Grafenrheinfeld	1225	6/74	1979	1981	2
Mülheim-Kärlich	1223	1/75	1978	1985	7
Grohnde	1294	6/76	1979	1984	5
Gundremmingen B	1244	7/76	1979	1983	4
Gundremmingen C	1244	7/76	1980	1984	4
Brokdorf	1290	10/76	1981	1987	6
Philippsburg 2	1281	7/77	1981	1985	4
Wyhl	1284	1/75	1979	1987?	8
Uentrop THTR	296	5/71	1977	1984	7
Kalkar SNR	295	12/72	1979	1985	6
				Total	58

Delays in nuclear power plant construction

Location	Election district	Votes won by the Greens (%)
Schleswig-Holstein		5,2
Brunsbüttel	Steinburg-Dithmarschen	4,7
Brokdorf	Pinneberg	5,9
Krümmel	Hgtm. Lauenburg-Stormarn	5,8
Niedersachsen		5,7
Unterweser	Delmenhorst-Wesermarsch	6,2
Stade	Stade	5,5
Grohnde	Hameln-Holzminden	4,5
Lingen/Ems	Unterems	4,6
Gorleben, Dragahn	Lüneburg-Lüchow-Danneberg	8,9
Gruben Asse und Konrad	Salzgitter-Wolfenbüttel	3,9
Nordrhein-Westfalen		5,2
Würgassen	Höxter-Lippe II	5,1
Kalkar	Kleve	4,4
Schmehausen	Hamm-Unna II	4,2
Gronau, Ahaus	Borken	3,9
Jülich, KFA	Düren	3,7
Hessen		6,0
Biblis	Bergstraße	4,9
Nukem Hanau	Hanau	5,6
Rheinland-Pfalz		4,5
Mülheim-Kärlich	Koblenz	4,5
Baden-Württemberg		6,8
Obrigheim	Rhein-Neckar	6,5
Neckarwestheim	Heilbronn	6,5
Wyhl	Emmendingen-Lahr	7,6
Philippsburg, KFK	Karlsruhe-Land	5,5
Bayern		4,6
Kahl	Aschaffenburg	4,9
Grafenrheinfeld	Schweinfurt	4,2
Isar	Landshut	3,6
Gundremmingen	Donau-Ries	3,8
Schwandorf	Schwandorf	3,9

How nuclear opponents voted in the last federal elections



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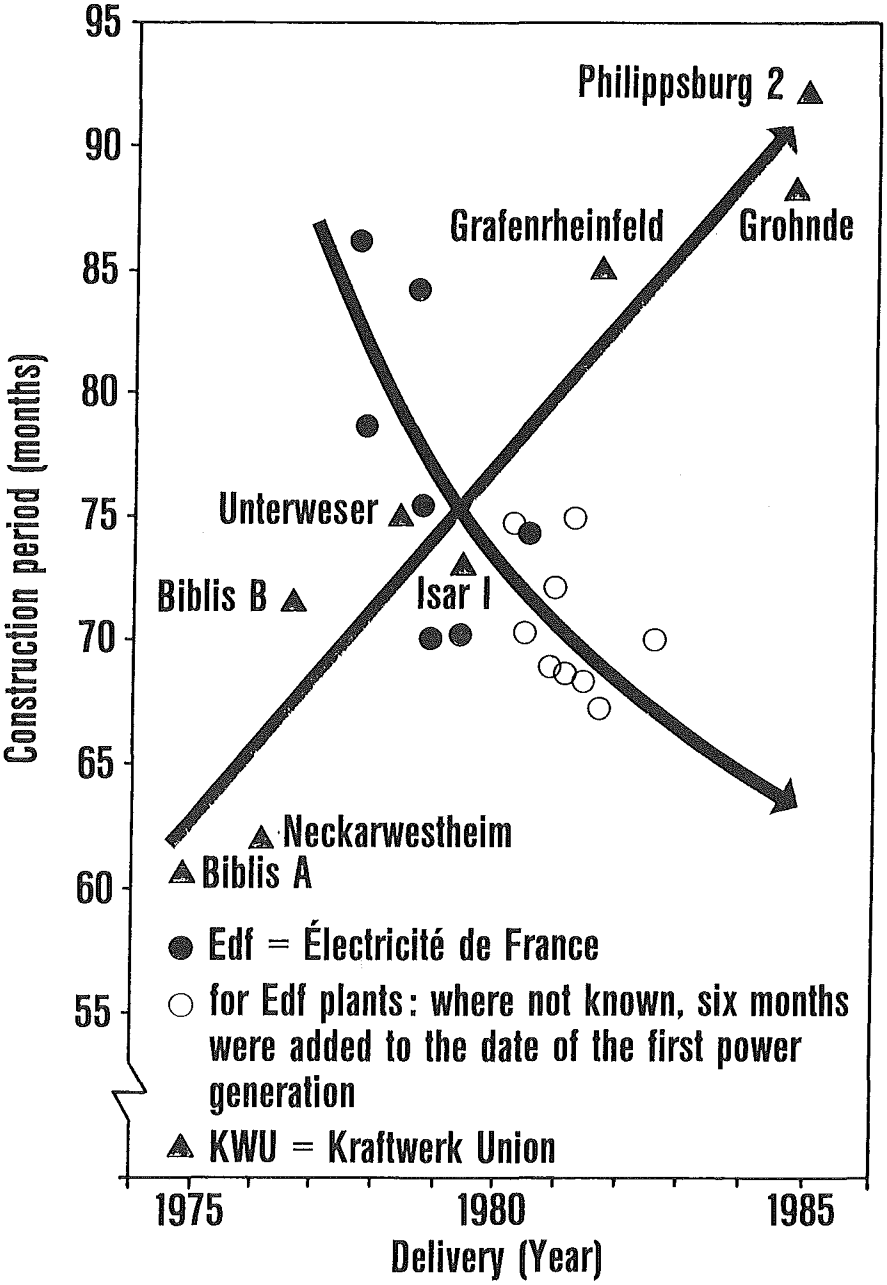
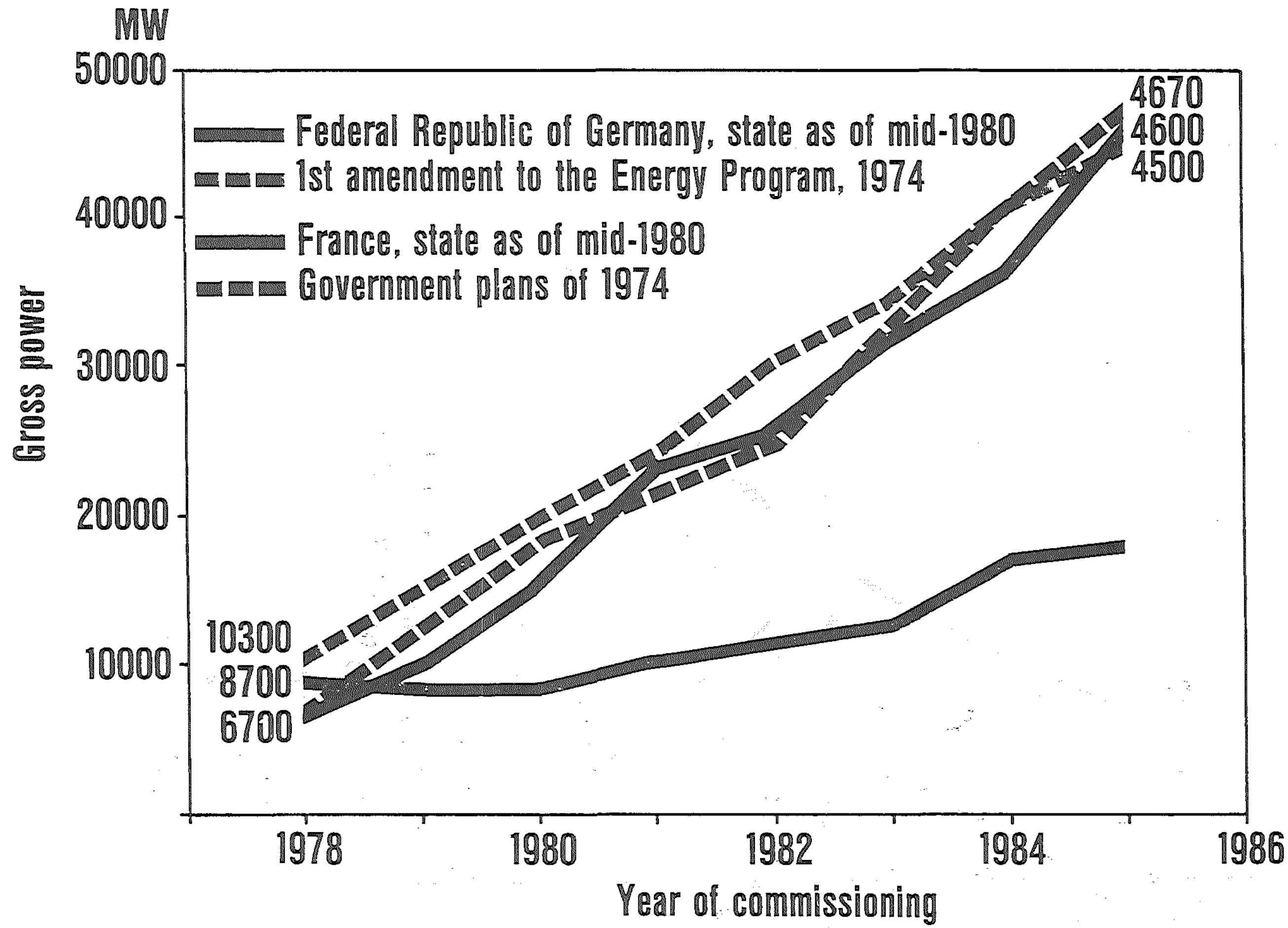
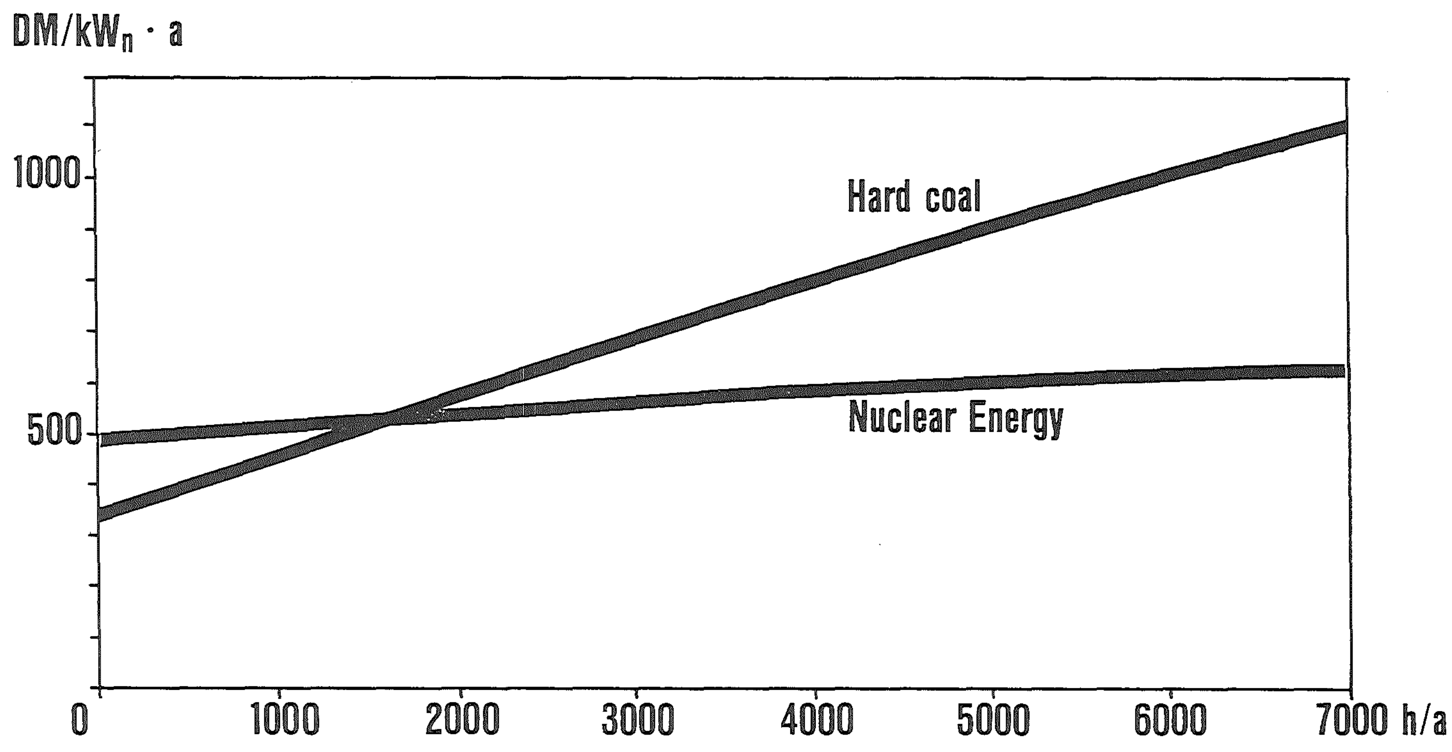
Attitude to nuclear power (American public)



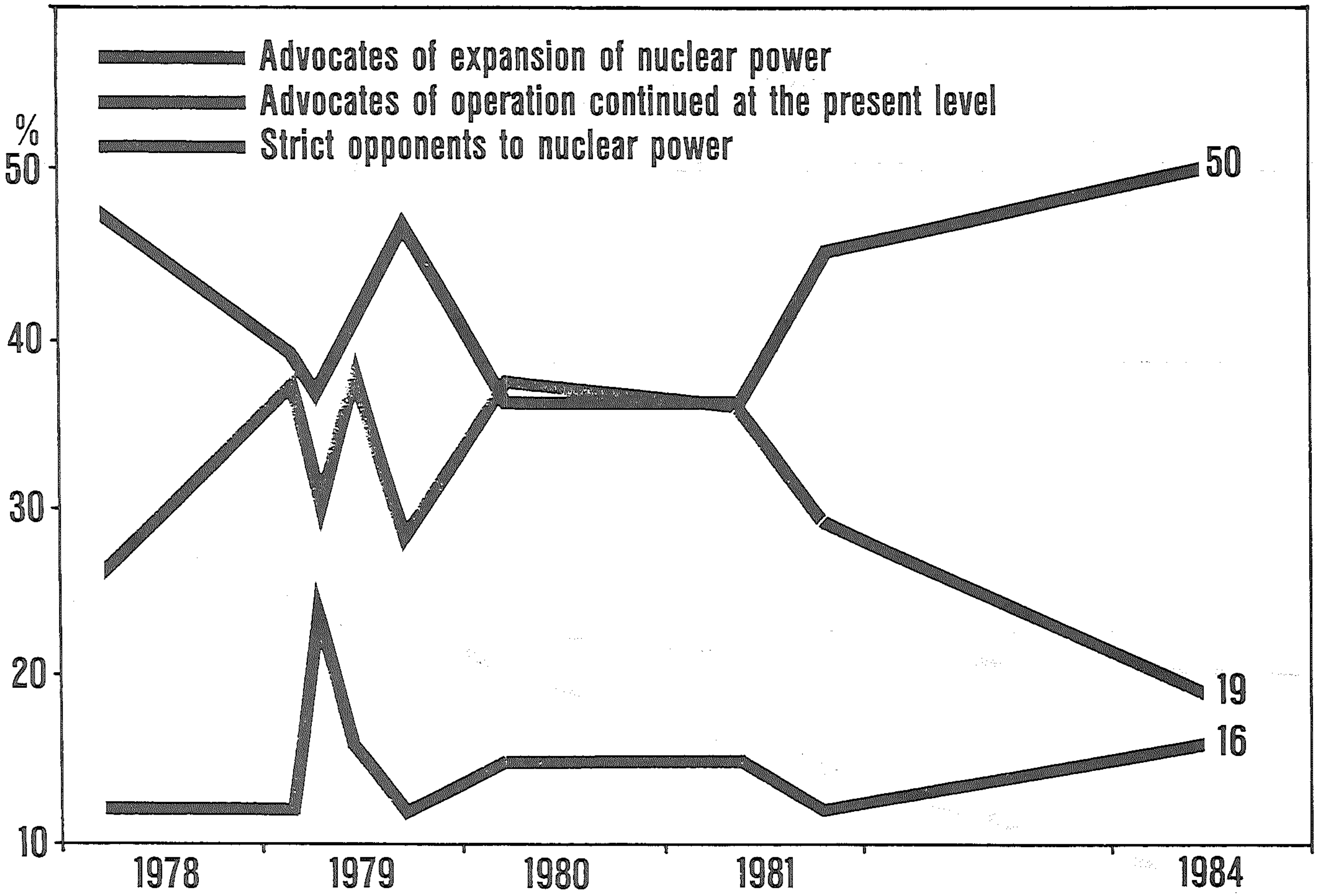
Comparison of construction times (german and french nuclear power plants)



Development of installed nuclear generating capacities



Electricity generating costs (coal fired power plants/nuclear power plants)



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Development of opinion groups in the nuclear energy debate

PROBLEMS ON ACCEPTANCE OF NUCLEAR ENERGY - ROOTS, DEVELOPMENT, AND VARIETIES IN DIFFERENT COUNTRIES

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Waste Management and Nuclear Safety
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Problems on Acceptance of Nuclear Energy - Roots, Development, and Varities in Different Countries

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Introduction

For a number of years the introduction of nuclear energy and its expansion have been accompanied by acceptance problems in a number of industrialized countries of the world. This behaviour seems to be to a certain extent a historical phenomenon. Since the beginning of technology and industrialization in the European countries nearly all innovations have caused fear to the population on the one hand and faith in progress on the other. In recent times this ambivalence has evoked a discussion about risk and benefit. But risk and benefit canot be measured in the same units. Normally it would be necessary to compare benefit and damage on the one side and on the other the risk which stems from a technology with the risk removed by that technology. Therefore the question must arise to what extent technology and industry has diminished the risks of everyday life. In former times man was forced to protect himself against the risks of nature. Today it is more necessary to protect nature from the technology developed by man. Nevertheless it can be said that technology has changed our life positively. Life expectancy has been increased by technology. The number of diseases has been reduced and epedemics have become very seldom. Technological developments played their role in shortening our working hours and in preventing the exploitation of animal and human labor. Industrialized states presently use an amount of energy comparable to a labour force of 12 workers per inhabitant. Technology and industrialization have played their role to improve the standard of living, improve health and to protect mankind from natural dangers and illnesses. At the same time technology and industry have introduced a number of new - hitherto unknown - risks for mankind. It is especially this potential which can lead to problems with the acceptance of these technological risks. If it could be shown absolutely clearly that the decrease in risk brought about by industrialization is by far bigger than the increase created by technology than it would be easy to come to the acceptance of new technologies. But this seems to be a very difficult task because objective measures of risks associated with technology are very difficult to come by and therefore it is not easy to convince the public.

This paper will show using the example of nuclear energy the different elements and viewpoints of a controversy created by a new technology. Risk estimation and perception is described as the basis of a study, comparing alternative points of view of public perception of nuclear energy of people from industrial states with those from developing countries. The analysis and the assessment of differences of attitude can be used to advantage for the situation in Indonesia.

Different Elements of the Nuclear Controversy

It is a striking feature of the nuclear controversy that its objectives, means, and methods changed frequently during its more than 10 years duration. In spite of the extreme heterogeneity of the groups supporting this controversy and despite the different interests governing it, it is possible to identify and to characterize a number of different topics between 1965 and today. The direction of impact on the public at large in the nuclear controvery has frequently changed in the course of years or has been handled by those involved with varying intensity (Figure 1). While in the first few years major importance was attached to nuclear safety, radioactive releases, the plutonium problem and questions of economy, the emphasis for the scientific field and in the public mind changed in later years. As far as nuclear safety was concerned public interest decreased in the 70s followed by a sharp increase in the year 1979 following the Three Mile Island accident. After that public interest in nuclear safety decreased again until it reached its highest level after the Chernobyl catastrophy. Nearly the same behaviour can be identified for the discussion about radioactive releases and emissions from nuclear installations. This question, too, slowed down in the 70s and gained new and high importance after Chernobyl. The plutonium issue has attained nearly stable importance during the last 20 years, whereas interest in economic aspects of nuclear energy, still comparitively low in the 60s, had a maximum value in the late 70s and again lost importance until now. In the mid 70s new emphasis was attributed to the problems of waste handling. The question of proliferation and the discussion about soft and hard technology is characteristic of the difference between nuclear energy and alternative energy sources. In the 80s the waste problem was increasingly important because of the more and more active discussion about the construction of a German reprocessing plant and the preparation of a site for a final waste respository.

Facets of the Nuclear Controversy

Looking at the nuclear debate in the Federal Republic of Germany between 1974 and today it is possible to identify and to describe various facets of this controversy and to analyse the results, achievements, and consequences. Whereas in the beginning of the nuclear age this new energy source enjoyed a favorable public which regarded modern technology with fascination and related it with national prestige, research reactors and the first commercial nuclear energy installations were constructed almost without any public discussion and could be put into operation. The first emergence of opposition to nuclear energy could be recognized in the United States in the late 60s. It spread to the European countries around the year 1973 as a consequence of the rising oil price and the resultant acceleration in the extension of nuclear energy.

Individual groups of opponents quickly joined up to form citizen interest groups which insisted on a participation in decisions concerning relevant questions in general and nuclear energy in particular (Figure 2). The population's "participation" in licensing procedures which was granted by means of hearings by the Atomic Law was exercised to an ever increasing extent and led to an exponential rise in the number of objections raised in connection with these procedures. These citizen interest groups obtained strong support in the press, radio and television. There the questions under discussion were represented as a topical problem by means of politically effective reporting. In the course of time these groups succeeded in influencing political parties and in forming their own political parties like the Green Party in Germany.

Another facet of the nuclear controversy can be identified in the effects on public opinion which could be initiated by opponent groups. At remarkably regular intervals information was published and discussed at length in the media. These news reports were produced on the one hand by erroneous interpretations of publications on various topics relating to nuclear energy, on the other hand with a lack of factual knowledge. Sometimes these reports referred to unobjective and incompentent sources.

In the nuclear debate it is frequently maintained that even experts were divided over many questions, implying the existance of a scientific controversy in these respects. It is true that a large number of scientists expressed their opinion on nuclear question, but they did not do so as competent experts on questions relating to nuclear energy but primarily as engaged citizens who, in their capacity as scientists in various branches outside nuclear energy enjoy high public esteem. Their opinion has a large influence on public opinion. The population in principle can not decide whether or not a scientist really is an expert in the nuclear field. Panel discussions in particular have gained in popularity because it is more interesting to see experts fighting on a panel than to hear reports on special topics of nuclear energy. Along with this development however, a general loss of confidence in scientists in general has taken place among the population. This could, however, not be capitalized on by the critics of nuclear energy. In 1975 half of those interviewed believed that the critics posessed an equally good knowledge as those active in the field of nuclear technology. In an interview in the year 1983 both proponents and opponents of nuclear energy attributed the greatest expertise and credibility to members of universities and nuclear research centres. Scientists engaged in citizen interest groups are given only third place, even by opponents, whereas proponents of nuclear energy rank them in 8th place.

In the early phase of resistance against nuclear energy sporadic demonstrations against siting decisions for nuclear power plants were observed. Since then the number of demonstrators went up to nearly 100,000 in a demonstration in the Capital of Bonn at the peak of the anti-nuclear movement in the year 1979. The first demonstrations took place without any use of violence but this changed in the course of time with violence directed against property being one of the early goals of the demonstrations. Violence against the police was gradually increased during these actions.

The activation of the political sphere for the problems of nuclear energy constitutes a further facet of the nuclear controversy. This facet is interesting in more than one respect. It illustrates anti-nuclear initiatives, it involves massive influence on parties and government, it manifests itself in elections influenced by the nuclear energy issue and in the foundation of new political parties by citizen interest groups, fighting for seats in parliament from whence to continue their struggle against nuclear energy. As a consequence there have been parliament debates on the peaceful use of nuclear energy, but as far as the German Parliament is concerned the result has always been a basic approval of nuclear energy. Nevertheless the problem of nuclear energy has been dealt with by all political parties on the occasion of their party congresses. Presently there is a great difference in the points of views in the different parties as far as nuclear energy in Germany is concerned.

Courts of justice were also appealed to most frequently in the course of the nuclear controversy. Court decisions interrupted the construction of nuclear power plants for months, prevented the commissioning of completed plants by more than 1 year or ordered building stops one of which has lasted till the present day. All levels of the judiciary up to the Federal Constitutional Court have been appealed to in the course of time. Although the opponents of nuclear energy were seldom ultimately successful in their appeals these appeals nevertheless have let to construction times for nuclear power stations almost doubling in the past few years, numerous building projects being interrupted for long time periods or not being put into operation after completion and the blocking other plants. This fact is one of the contributions to considerable cost increases for nuclear installations in Germany.

Risk Estimation and Perception

In a previous paper [1] presented 2 years ago, it was mentioned, that the general public assesses risks in a different manner from the risk evaluation of experts, who work on the basis of scientific risk definition. To find out the reasons for this descrepancy it is necessary to point out the important factors which people apply in their specific evaluation of risks. In a number of investigations the analyses determined 5 topics as important factors in risk perception.

- Qualitative risk features,
- Catastrophe potentials,
- Beliefs about the type of consequences,
- Social values,
- Personal characteristics.

Voluntariness seems to be the most important qualitative risk feature. Freedom of choice in the acceptance of risk is one of the reasons that a risk source which is voluntarily accepted may show a 1,000 times higher loss rate than risks which are imposed by society. This can explain that cigarette smoking and automobile traffic are much more easily acccepted than nuclear energy in spite of the fact that the number of deaths by lung cancer or heart deseases due to smoking or the number of deaths by traffic accidents is much higher than the number of people killed by nuclear energy even in a catastrophic accident.

Great difficulties in acceptance of nuclear energy result from the believe that nuclear energy has an extremely high catastrophe potential. It is true that similar catastrophe potentials are associated with a big number of technologies used by highly industrialized nations, for instance chemical industry, energy production, automobile and air traffic, or biotechnology. But this potential is only taken seriously as far as nuclear energy is concerned because it is described in an highly exaggerated manner by the opponents of this technology.

Beliefs about consequences attain more negative values for nuclear energy than they do for the use of coal, solar energy or wind. The fact that nuclear energy does not contribute to the problem of acid rain and its effects on the forests, and the role of nuclear power for solving future energy problems is not enough to prevent a negative effect on the public. In spite of accidents in coal mines, the pollution of air by emission of SO&hd.2&hu. and NO&hd.x&hu.and the future problem of CO&hd.2&hu. coal and other fossile energies have a generally positive public image.

Personal characteristics can be measured for instance in the difference between what energy option or technology is wanted and how far this desire can be realized in the technical future. Furthermore it is always necessary to establish a relationship between the ideas people have about risks and the object causing them. Thus the atomic armement or the Chernobyl accident with the radioactive contamination of countries lying more than 1,000 miles away from the nuclear reactor site paints a more negative picture of everything associated with nuclear energy than a positive one.

From Normality to the Chernobyl Syndrom

In spite of all these problems nuclear energy was accepted in the Federal Republic of Germany in the first half of the 80s. After the last election nuclear energy was not considered to be a topic for political discussion. It was possible to describe nuclear energy just as a 'normal' method of energy production. At the end of 1984 a total number of 20 nuclear stations (3 prototypes and 17 commercial plants with a capacity of about 17,000 MWe) produced nearly 1/3 of the total electricity in Germany and contributed more than 10 per cent to the primary energy production in our country. Normality does not mean that nuclear energy was not discussed any longer. It was recognised that all forms of energy production had their advantages and disadvantages. The fossil fuels caused acid rain and were therefore a great danger for the forests. The alternative sources had the disadvantage of low potential and high price, and nuclear energy the disadvantage of radioactivity, the so-called plutonium economy and the aspect of proliferation.

This all changed immediately after April 26, 1986, when the accident occurred in one of the four nuclear power plants in Chernobyl, USSR. Since then, the fear of nuclear energy in the public has grown and the overwhelming majority suddenly wants to abandon nuclear energy. Because of the fact that the radioactive contamination caused restrictions in fruit and vegetable consumption, the European population felt the consequences of a nuclear accident very close to home, although the accident was very far away. In the forefront of discussion was the question whether an accident like that in Chernobyl could also occur in a nuclear power plant of the Federal Republic of Germany. Anti-nuclear organizations, together with political parties, thought about the possibility of forgoing the utilisation of nuclear energy. In the course of this consideration the great differences in nuclear safety between German and Russian power plants had been apparantly forgotten. On the other hand it was very difficult to make these technical differences clear to the public. The physical instability of the Russian reactor in which a temperature increase leads to a power excursion, the poor design of the emergency core cooling system (which would never fullfill the demands of German safety guidelines) and the absolute absence of a tight containment to retain radioactive fission products could not be conveyed to the public. According to the report of the USSR state committee on the utilisation of atomic energy about the accident at the Chernobyl nuclear power plant [2], which has been presented to the IAEA in August 1986 the operating personnel of the reactor blocked the safety system of the reactor in order to perform an experiment with a turbine. One can therefore argue that this type of accident is impossible in a reactor which is built according to German safety rules and guidelines. Whereas some political parties and interested groups in our country want to abandon nuclear energy without regard for cost, unemployment, industrial situation and the country's position in international commerce, the majority of the German population is not in favour of this, as the latest polls performed in the Federal Republic of Germany show. According to these polls 57 per cent are not in favour of foregoing nuclear power, whereas 32 per cent do so [3]. In the public discussion, the question of safety differences in nuclear power plants between Germany and the neighbouring countries is receiving more and more attention. Our country, with its 20 nuclear installations, is surrounded by nearly 200 nuclear installations in other European countries. Therefore, once again safety is one of the key issues of nuclear energy. The trend is going toward a so-called forgiving technology in the nuclear field which does not endanger the environment even in the event of human error.

The Attitudes towards Nuclear Energy - Comparison between Industrial and Developing Countries

In a paper two years ago it was illustrated that there exist distinct differences in public attitudes towards the nuclear energy option among people from industrial societies and those living in developing countries [1]. In that paper some important influences governing the attitudes of people in developing and industrialized countries where obtained by comparing the answers of students of technical subjects in Germany, Japan and the Philippines to questions concerning nuclear energy [4]. Today, additional results for Latin American students permit a more comprehensive look to the situation [5]. The student samples were taken from technical faculties of universities. In Germany 150 students were interviewed, the Japanese students comprised a group of 120, the Philippine students were 174 in number and the students from Latin America were, with 684, the largest group sampled. As a general remark it can be concluded that the Japanese students are predominantly in favour of the use of nuclear energy, the 3 other student-samples from Germany, the Philippines and from Latin America include both interest groups, proponents (PRO) and opponents (CON). In Latin America the distribution between PRO and CON was nearly equal.

To measure the attitude of the students towards nuclear energy directly the technique of the semantic differential was used. This technique makes use of the evaluation of bipolar descriptors and provides interesting information about the respondents' perception of nuclear energy. The students were asked to rate themselves concerning the relevant descriptors on a 7-point-scale ranging from -3 (i.e. to accept the negative descriptor) to +3 (for the positive one). Figure 3 shows the list of these bipolar descriptors and the mean ratings given for each country. The sequence of the descriptors on the figure is determined by the mean value for the Latin American respondents in descending order. The favourable Japanese respondents (open circles) see the use of nuclear energy as very important and useful, quite good, modern and worthwhile, although they realise that it is quite controversal and slightly dangerous. In contrast to this relatively clear perception, Philippine students (closed circles) view nuclear energy as quite wrong, oppressing and useless, whereby they seem to acknowledge that the nuclear energy source has some importance. The German students (closed triangles) have the least strong feeling about the use of nuclear energy, perceiving it as quite modern, useful, fairly important, worthwhile, but slightly dangerous, too. The Latin American students (open triangles) are of the opinion that nuclear energy is modern, quite useful, important and worthwhile. But they see it as an unpredictible harmful energy source which might be controversial and dangerous.

For the Latin American students the semantic differential method was applied for five energy sources: nuclear, solar, hydro, coal and oil. The results are depicted in figure 4. The order of descriptors is the same as in the previous figure and is determined by the mean values for nuclear energy in descending order. It is clearly seen that the Latin American students have given the highest positive ratings to solar energy, closely followed by hydro. The fossile fuels such as oil and coal are generally rated as less positive than these. As far as nuclear energy is concerned ratings tend to be low. Most of the values are located in the range between -1 to +1 which indicates that the opinion is, to a certain extent, undecided. Solar, hydro and coal are perceived as right, beneficial, important, useful and acceptable. Nuclear energy is appreciated as useful and modern, but the reservations are expressed in that nuclear energy is seen as dangerous, harmful, unpredictable and controversial. It seems that the interviewed students relate negatively to nuclear energy whereas they do not perceive other energy options with the same degree of criticism. Solar and hydro are to a great extent energy sources which people desire today and especially in the future.They are used to coal and oil and they feel that they can use these fossile energy sources together with a lot of other countries. Nuclear energy is ambivalent. There are positive and negative characteristics, as far as risk and benefit is concerned, in nearly every country of the world. So in every nation where nuclear energy is used or will be used in the future it seems necessary to inform people, especially the young intelligent generation, about the real advantages and the real disadvantages of nuclear energy. Only in this way will objective assessment be forthcoming.

But there is another interesting fact which was revealed by the investigation. The Latin American students were nearly equally divided into opponents and proponents of nuclear energy. So a semantic differential could be obtained for the CON and the PRO-group. This is shown in figure 5. It is easy to see that the main values of the PRO-group are predominantely in the positive range whereas the CON-group averages are mainly negative. However, some concerns about nuclear energy have also been expressed by the PRO-group. Both groups agree that nuclear energy is very modern way of energy production. But for nearly all descriptors the differences between the CON and the PRO-groups ratings are 2 points or more on the possible 7 point scale. The difference is very small only as far as solar, hydro, coal and oil is concerned. Here the ratings of the positive and negative groups are very close together with the greatest difference for oil, amounting to nearly 1 point on the 7 point scale. This shows once again that only nuclear energy seems to be controversial in public opinion in general and in students opinion in particular. The slight differences in the attitude and the acceptance of other energy sources make nuclear energy so problematic in the thinking of people.

Another possibility to obtain information about the attitude of people towards energy production methods is the definition of beliefs and their importance in deciding to be in favour or against one of these methods. A belief, in the way it is used in this analysis, represents the information a person has about a given object and to what degree this information is associated with the object in question. Figure 6 shows which beliefs are chosen to be of highest importance by the different samples of interviewed students i.e. in the first 6 ranks. This gives information about the attributes to which the highest rate of awareness of the respondents about the current issues in the nuclear debate is associated. There were in all 30 attributes on the basis of which the students could make their rating. The analysis indicates the degree to which the respondents are informed on the subject of nuclear energy production.

Taking the first 4 top ranking issues for each sample, it can be seen that Philippine and Japanese respondents see both risks and benefits of nuclear energy as of relevance whereas German respondents mainly are interested in the benefits. With regard to the priorities expressed by Philippine students, they are concerned with potential health impacts and large accidents on the risk side, and on stimulation of scientific, technological research and technical progress on the benefit side. Japanese students paid attention to the management of dangerous wastes and to large accidents but also recognized the importance of the stimulation of scientific and technological research and a cheap energy source. In Germany students appear to be concentrating their attention on the beneficial aspects of generating nuclear energy and on conservation of natural resources, long-term solution of energy needs, increased employment and stimulation of research. This might be interpreted as an indication that their interest in the benefits of nuclear power takes precedence over their beliefs regarding risks. Regarding the lowest priority assigned by the 3 samples, which is not shown in the figure, they all agree that concerns about a consumption oriented society are not relevant to the debate about nuclear power.

For the Latin American sample the situation is slightly different. For the total sample the most important concerns were about the harmfulness to future generations, followed by the management of dangerous wastes, the impact on peoples health and the hazards which people can not influence by their own actions. The possiblity that nuclear energy might be stimulating scientific and technological research occupies only fifth place in the importance ratings. The issues regarding the consumption oriented society and the diffusion of knowledge for construction of weapons are given the least importance in the nuclear debate and are therefore not shown on the figure.

The Latin American sample was divided into the PRO and CON-group on the basis of their distinct attitudes. Inspection of the ranks assigned to the attributes by the CON-group shows a much higher similarity with the total sample than the PRO-group does. In particular the top 4 ranks include the same attributes. Only the fifth rank is totally different. The highest ranking is given by the CON-group to concerns about potential risks. On the other hand the PRO-group gives first priority to technical progress, stimulation of scientific and technological research, the promotion of the industrial development and the economic independence of the country. These attributes can be described in general as technical, economic and national benefits.

This situation shows that there exists to a certain degree a concern among the proponents of the nuclear energy as to potential risks and difficulties in the management of nuclear energy. These concerns are articulated by the proponents along with the benefits. The opponents, on the other hand, focuss their attention purely on the negative aspects of nuclear power production and give little or no credit to its benefits. In this sense, the CON-group appears to represent the general feelings of the sample as a whole more than does the PRO-group.

Conclusions

With regard to the experience of more than 10 years of nuclear controversy in an industrialized country it seems to be very difficult to give advice for actions to improve acceptance. Moreover this might be even more difficult to give this advice for the situation in a developing country. For every nation the prerequisits, incentives, conditions and plans for the future are different. The social situation, the economic conditions, the resources and the political facts have to be analyzed specificly and taken into consideration by improving acceptance for new technologies and especially acceptance for nuclear energy. So it was more the intention of this report to show some deciding factors for direct activities, the elements which have to be recognized, the methods which can be used, and to show how other people, especially students, behave in industrialized and in developing countries. Without a better knowledge it can not be decided precisely which of the presented countries, Japan, the Philippines or the Latin American countries are representative for the situation in Indonesia. But the reader will certainly be able to take this decision and to take advantage of the results and findings of the different studies reported about in this paper. Therefore this presentation might be the analytical background for future actions specifically focussed on the Indonesian people which enables it to make a profit of nuclear power as a vigorous energy source for further development and for the industrialization of the country.

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E. Swaton, O. Renn

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E. Swaton

IAEA, 1985

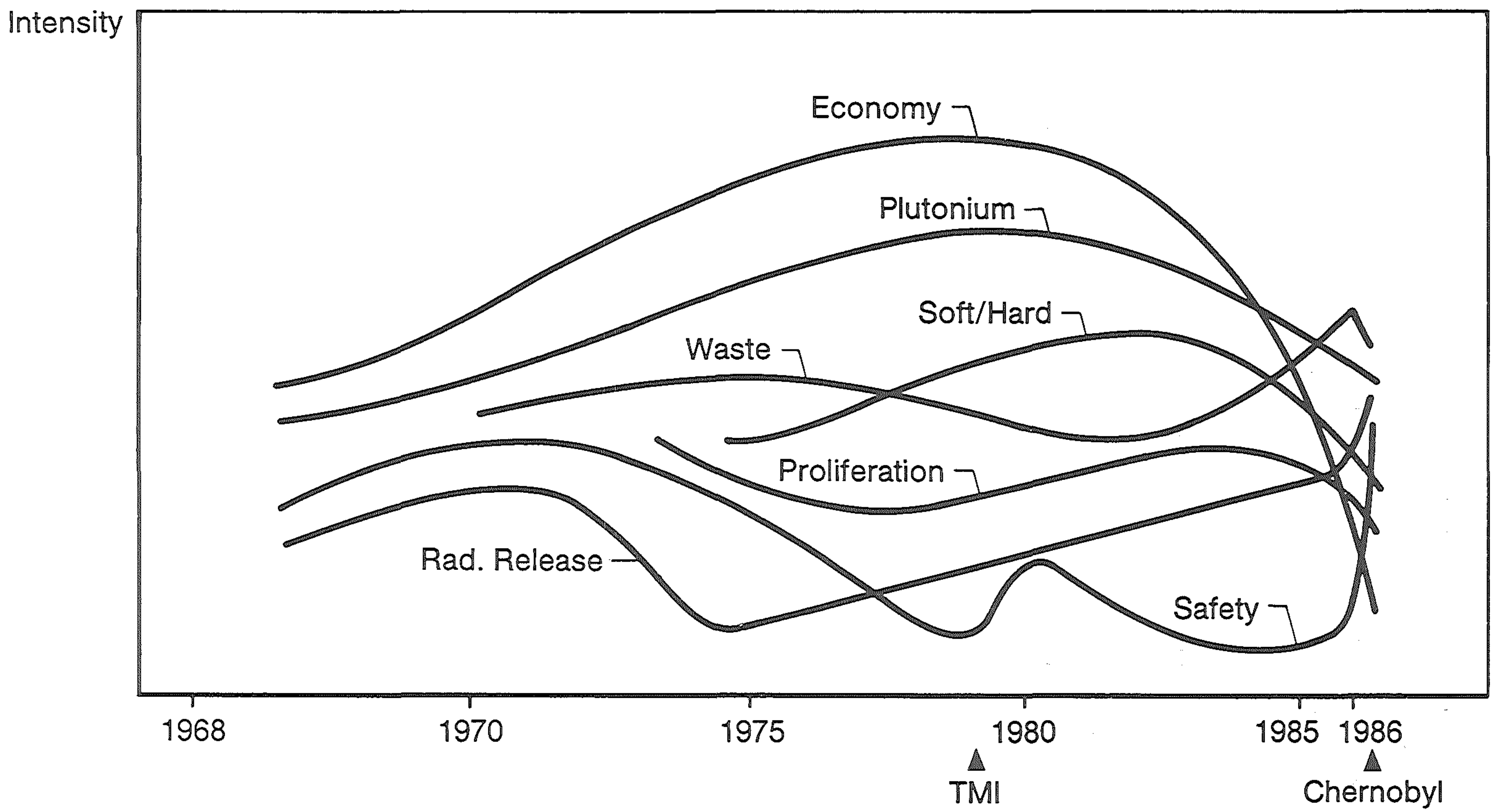
Intensity
Economy
Plutonium
Soft/Hard
Waste
Proliferation
Rad. Release
Safety
1968
1970
1975
1980
1985
1986
TMI
Chernobyl

FIGURE 1

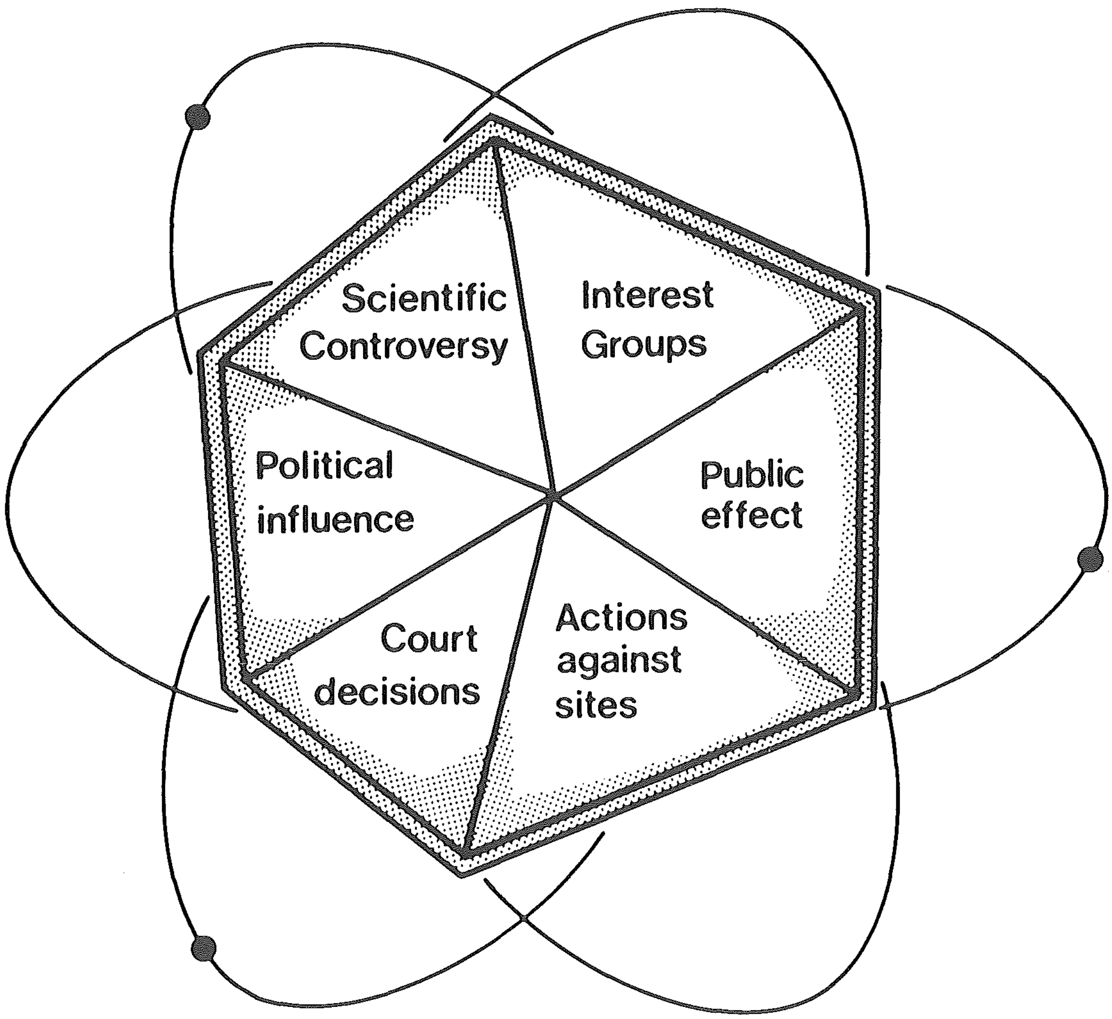
Scientific Controversy
Interest Groups
Political influence
Public effect
Court decisions
Actions against sites

FIGURE 2

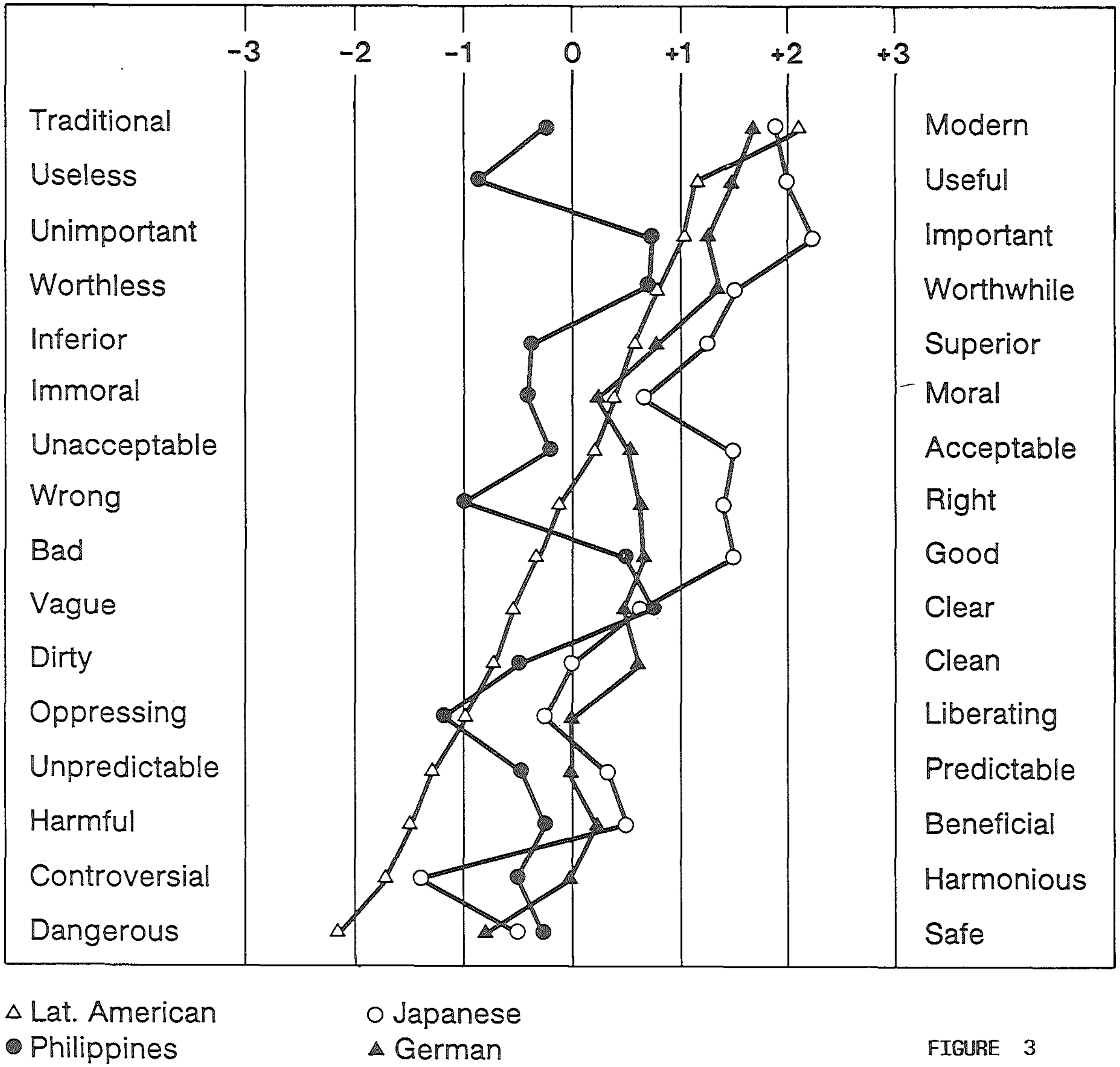
-3
-2
-1
0
+1
+2
+3
Traditional
Useless
Unimportant
Worthless
Inferior
Immoral
Unacceptable
Wrong
Bad
Vague
Dirty
Oppressing
Unpredictable
Harmful
Controversial
Dangerous
Modern
Useful
Important
Worthwhile
Superior
Moral
Acceptable
Right
Good
Clear
Clean
Liberating
Predictable
Beneficial
Harmonious
Safe
Lat. American
Philippines
Japanese
German

FIGURE 3

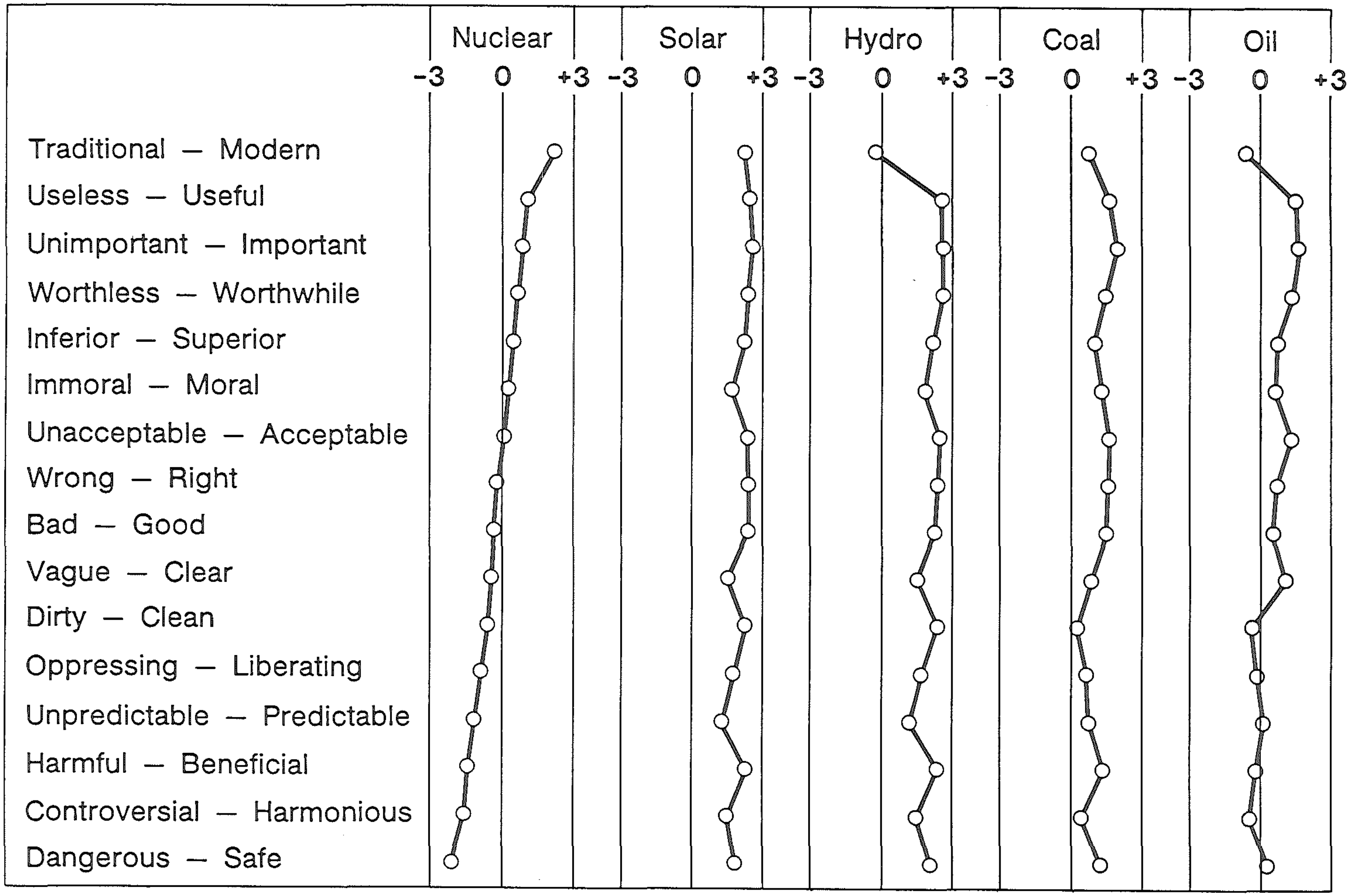
Nuclear
Solar
Hydro
Coal
Oil
-3 0 +3
Traditional — Modern
Useless — Useful
Unimportant — Important
Worthless — Worthwhile
Inferior — Superior
Immoral — Moral
Unacceptable — Acceptable
Wrong — Right
Bad — Good
Vague — Clear
Dirty — Clean
Oppressing — Liberating
Unpredictable — Predictable
Harmful — Beneficial
Controversial — Harmonious
Dangerous — Safe

FIGURE 4

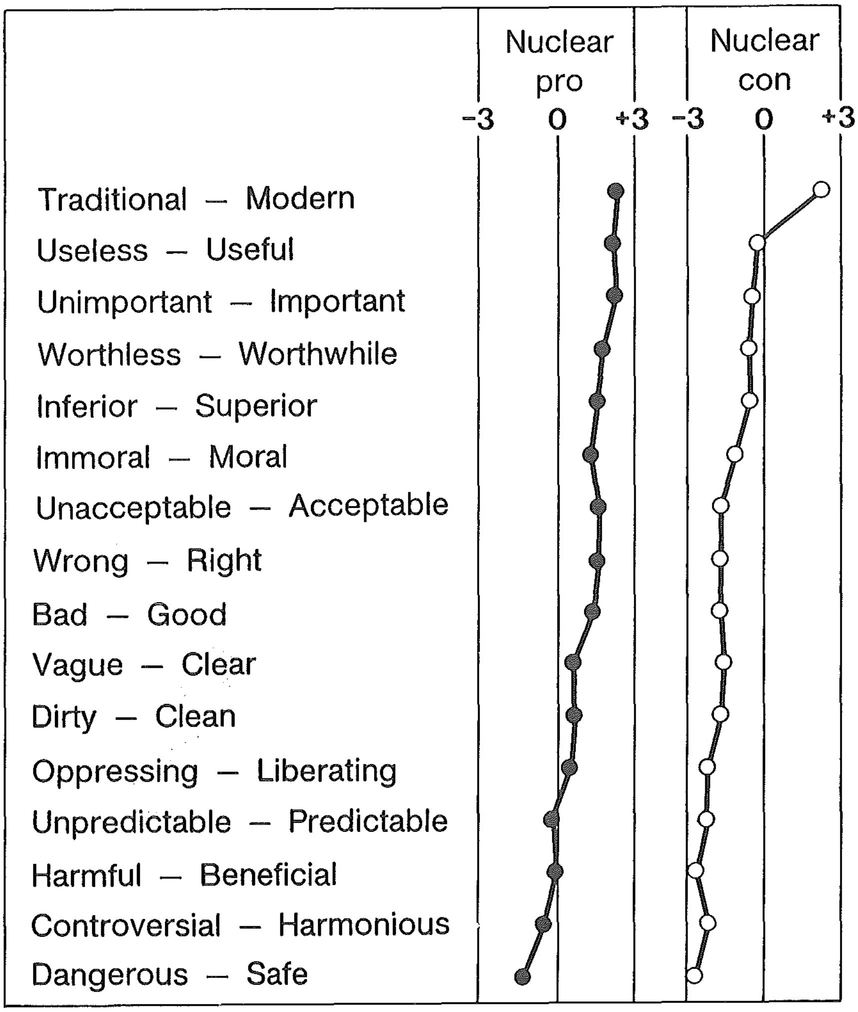
Nuclear pro
Nuclear con
-3
0
+3
-3
0
+3
Traditional — Modern
Useless — Useful
Unimportant — Important
Worthless — Worthwhile
Inferior — Superior
Immoral — Moral
Unacceptable — Acceptable
Wrong — Right
Bad — Good
Vague — Clear
Dirty — Clean
Oppressing — Liberating
Unpredictable — Predictable
Harmful — Beneficial
Controversial — Harmonious
Dangerous — Safe

FIGURE 5

	Phil.	Japan	Germany	Total Lat.Am.	Pro Lat. Am.	Con Lat. Am.
Being harmful to future generations	12	10	13	1	13	1
Leading to technical progress	4	8	7	10	1	20
Requiring management of dangerous wastes	14	1	6	2	11	4
Helping to reserve natural resources	5	11	1	22	14	19
Exposing people to hazards without participation	7	13	16	4	19	2
Having and impact on people's health	1	6	11	3	15	3
Providing a cheap energy source	17	2	5	23	10	24
Leading to accidents which affect many people simultaneously	3	3	12	6	17	6
Being a long-term solution to energy needs	9	7	2	19	8	25
Leading to increased employment	6	11	3	12	7	17
Stimulating scientific and technological research	2	3	4	5	2	13
Involving hazardous agents not detectable by human senses	9	5	10	8	22	8

FIGURE 6

Public Relations Activities of the Karlsruhe Nuclear Research Center - A National Research Center Contributes to Opinion Forming

K. Körting

Contents:

1. The Karlsruhe Nuclear Research Center.
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3. Administrative Structure of the Public Relations Department
4. Public Relations Instruments.
4.1 "KfK-Hausmitteilungen," a House Journal.
4.2 Accident Information.
4.3 "KfK-Nachrichten," a Scientific Journal.
4.4 Press Releases.
4.5 Exhibitions and Fairs.
4.6 Guided Tours.
4.7 Nuclear Energy Information Staff.
4.8 Corporate Displays and Publications.
4.9 Conference Office.
5. Influencing Public Opinion.

1. The Karlsruhe Nuclear Research Center

The Karlsruhe Nuclear Research Center (KfK) was founded in 1956. This national research establishment and others were created roughly at the same time in order to promote the peaceful uses of nuclear energy in the Federal Republic of Germany by research and development work in the nuclear field.

The Nuclear Research Center is organized as a private company (Gesellschaft mit beschränkter Haftung, GmbH, under German law) in which the Federal Government holds a 90%, the Baden-Württemberg State Government a 10% interest. The KfK site at present covers an area of approx. 2.5 km^2 (Fig. 1). The Center's 52 administrative units are arranged under five executive headings with specialized scientific and technical functions (Fig. 2). Most of the twelve main activities of KfK (Fig. 3) deal with nuclear subjects, but are increasingly supplemented by non-nuclear topics. The Center at present has a staff of approx. 4100 persons and an annual budget of approx. DM 700 million.

2. Basic Principles of Public Relations Work

Public relations work is a dialog between institutions and society carried on in an attempt to generate understanding and appreciation of the activities of those institutions. In concrete terms, this means that the external image of an institution is preserved and improved, respectively, and the internal corporate identity is strengthened. In a national nuclear research center, this dialog is influenced especially by the following environment (Fig. 4):

- Communication in public relations is about highly specialized research findings.

- Research in the nuclear field is bound to be accompanied by nuclear incidents and accidents.

- Government institutions have the duty to inject information into the ongoing debate about the acceptance of nuclear technology.

- Research - its public relations activities included - costs public money.

From these contributing factors a number of major points and administrative requirements can be derived which must be met in public relations work:

- Understandability and clarity is essential in a dialog with the general public, in the presentation of recent research and development findings as well as in reports about accidents or incidents or descriptions of the current state of the art in nuclear technology. As a rule, this requirement is met only by public relations experts; research scientists are seldom prepared to translate into general, understandable language the scientific and technical jargon used in the field.

- Openness and frankness, i.e., communication without reservation, is indispensable to establishing an atmosphere of trust with the public and representatives of the media. As far as research findings are concerned, this frankness can be taken for granted, for it is required under the statutes of KfK. However, especially when accidents or incidents are involved, absolutely open and complete reporting of the facts by the Public Relations Department is the only way in which to counteract one of the frequently practiced tenets of the media: "Only bad news is good news." Moreover, experience tells that a less-than-open information policy in such cases is bound to produce a negative basic attitude vis-à-vis that institution.

- Uniformity, i.e. speaking and writing in one voice is a confidence building measure whose effectiveness should not be underrated, especially in controversial discussions about nuclear technology. This absence of contradictions in written or verbal statements is supplemented by a uniform outward appearance, which is one of the preconditions for achieving high scores in public awareness.

- Controllability of the impact of public relations measures must be ensured if funds ar to be spent effectively. Despite great efforts, the impact of such measures can be gaged objectively only in some narrow fields.

- Initiative or taking the lead in informing the public is particularly important, not only in positive, but also in negative cases. Taking the initiative especially in those latter cases will create confidence, even if it will not entirely avoid critical articles in the press. The impression created by negative news can be compensated only by a high rate of positive news. It is known from experience that a high rate of news production requires the proper initiative on the part of public relations departments.

- Freedom of action is needed for quick reactions to the media. It is a well known fact that reacting quickly is very important in establishing good working relations with the media. Freedom of action also means that public relations is not only a mediator, but also a source in the communication process.

3. Administrative Structure of the Public Relations Department

Public relations departments are given the necessary freedom of act by being placed in the company hierarchy so that they report to top management. At the Karlsruhe Nuclear Research Center, the Public Relations Department (Fig. 5) directly reports to the Chief Executive Officer. The Head of the Public Relations Department acts as spokesman of the Center in the public. This is an independent function, which requires him to be fully informed of the work of all units and of the policy goals of the Executive Board. At KfK this is ensured by the Head of Public Relations attending the meetings of the Executive Board and of its consultant bodies. Other conditions for achieving adequate freedom of action are good personal contacts with the scientists in the different units and also scientific and technical knowledge of their activities.

Administratively, the Public Relations Department is arranged in specialized areas managed by expert staff (Fig. 5). The Department has a staff of twelve persons, among them two scientists, one editor, two graphic artists, and two photographers. Annual expenses amount to approximately DM 2.2 million (state as of 1985). The activities of the Public Relations Department are planned ahead in detail for a period of approximately 18 months. Effectiveness is monitored on the basis of an annual activity report.

4. Public Relations Instruments

The key tools used by the Public Relations Department are listed in Fig 6. These are the "KfK-Hausmitteilungen" as a house journal, the reports distributed about accidents and incidents, the "KfK-Nachrichten" as a scientific journal, press releases, exhibitions, guided tours for visitors, the Nuclear Energy Information Staff, the production of displays and publications, and a Conference Office. These tools are arranged in a sequence representing the transition from more internal to more external effects. Figure 6 also contains a statement on effectiveness monitoring, indicating to what extent effectiveness can actually be measured in objective terms or is restricted to a more subjective evaluation. This will be described in greater detail below. Figure 6 does not contain some other essential tools not routinely applied, such as improving community relations by organizing meetings with the mayors of the neighborhood communities or producing a film informing about the Center every 5 to 6 years or updating the permanent exhibtion for the benefit of visitors.

4.1 "KfK-Hausmitteilungen," a House Journal

The house journal, "KfK-Hausmitteilungen", (Fig. 7) informs tahe staff about what goes on at the Center and is important or worth knowing. Although most of its impact is internal, some 20% of the approx. 6000 copies printed of each issue are mailed to former staff members and to friends of the Center. The journal is published in six issues annually, each of them comprising an average of 35 pages. The editors enjoy freedom of the press and receive no instructions from the Executive Board.

An attempt was made to conduct impact research on an objective basis. Unlike commercial publications, the acceptance of our house journal cannot be judged on the basis of its circulation. Consequently, the topics the personnel want to be covered in a company journal were listed in the format of an interest profile. The editors try to adhere to this profile of readers' interests on a long-term basis by selecting the appropriate topics and giving them the desired space. The outcome of this procedure is represented in Fig. 8. Five areas of interest were defined for the contents of articles to be published in the company journal: "The Working Environment at KfK" encompasses the activities of the staff except for those treated under "Research and Development." Other headings are "Social and Personnel Matters," "Corporate Policy," and "Hobbies and

Sports Activities." Averaging various profiles of interests assumed to be plausible for various groups of staff members results in a target profile of the interests of the staff of the whole Center, which should be catered to in the information mix published in "Hausmitteilungen." It appears that articles about hobbies of staff members and sports activities rank at the bottom of the sale of interests, while the working environment of the Nuclear Research Center, which affects by far the largest number of staff members, seems to be the topic arousing the greatest interest. The articles published in the company journal can be classified under these areas of interest and can then be weighted with editorial factors as far as reading appeal and frequency of publication are concerned. The average of the information contained in all issues of "Hausmitteilungen" in the period 1978 - 1985 more or less corresponds to the demand profile. Individual issues of the journal may greatly deviate from that profile, as the low statistical population can cause considerable variation.

4.2 Accident Information

The information disseminated to staff members in cases of accidents, of which Fig. 9 shows a specimen copy, is an attempt to provide information to the staff as quickly and as factually as possible by notices put on the bulletin boards. At the same time, this information is transmitted by telephone to representatives of the local press. Consequently, this type of information has both internal and external impacts.

Classical accidents at work, especially if personnel injuries are involved, must be reported to the supervisory authorities and the insurance companies. The press take little interest in such events unless spectacular property damage or major injuries of personnel are involved. In the nuclear field, however, accident or incident is a term encompassing all events which deviate from the routine scheme of operation and which must be reported to the supervisory authorities with different degrees of urgency, depending on their relevancy to the safety of the facilities involved. Unlike conditions in the classical industrial sector, the press take a keen interest even in very minor incidents in the nuclear field. KfK works by the rule that all events which must be reported to the authorities will be published as accident information, if persons were endangered by exposures to radioactive substances or direct radiation or if there had been a risk of such exposures, or if such troublesome terms as, e.g., plutonium were mentioned in this connection.

Effectiveness monitoring in this field can be conducted on an objective basis. Fig. 10 shows that the frequency of articles reporting on such events with a negative bias has decreased greatly.

However, it must be pointed out that it took several years for this open information policy to be fully accepted internally and appreciated properly by the representatives of the media in matter-of-fact reporting. Incidentally, 1985 shows a considerable renewed increase in negative reporting. After a long period in which nuclear technology had been taken almost for granted we now recognize a growing sensitivity of the press, triggered probably by the renewed discussion this year about construction of a German reprocessing plant. Also, we anticipate another rise in negative reporting in 1986 as a consequence of the Chernobyl event.

4.3 "KfK-Nachrichten," a Scientific Journal

The scientific journal published by the Nuclear Research Center, "KfK-Nachrichten" (Fig. 11), is among the science periodicals in the Federal Republic of Germany with the highest circulation. It provides information about research activities at the Nuclear Research Center on a scientific level, but written so as to be understood also by other disciplines. Two thirds of the roughly 4500 copies printed are distributed externally, some 5% of these internationally. Effectiveness monitoring in this field is mainly subjective. We conclude form the external demand for "KfK-Nachrichten" and from the journal's use a s forum for scientific publication that it has been accepted as one of the major factors contributing to the positive image of the Nuclear Research Center.

4.4 Press Releases

Press releases are the most important tool in external public relations work. Fig. 12 shows a specimen copy. The Public Relations Department issues approximately 40 press releases per annum, most of which contain reports about scientific and technical work conducted at the Center. The Executive Board does not exercise any influence over the wording. The press releases are meant to achieve the broadest possible coverage in the daily press.

The attention the national press is devoting to the Center is measured with the assistance of a press clipping service and is documented in semi-annual press coverage reports. These reports contain reprints of all press clippings mentioning the Nuclear Research Center, arranged both by source and by tendency with respect to public impact. Fig. 13 shows the cumulated press resonance of the Center since 1978. Press activities have been greatly intensified since 1977. On an annual average, some 2700 clippings are registered in which the Nuclear Research Center is mentioned. Samples have indicated that these clippings represent an annual newspaper circulation of approximately 115 million copies. Special attention should be drawn to the relatively small average fraction of 3% of reports with a negative bias, most of which originate with newspapers whose political attitude is antinuclear, and a relatively high percentage of positive reports amounting to an average 30%.

Fig. 14 shows the press statistics for 1985. The press clippings collected are arranged in accordance with the topics covered: press clippings based on press releases by KfK or on accident reports, and those articles in which KfK is only mentioned in connection with the general subject of a report. Interestingly, more than half of the clippings are based on reports initiated by the respective press releases, with an impressive percentage of positive reports in this category. This is experimental proof of the benefit of aggressive press work.

Press activities in the seventies were supplemented by information courses for journalists on topics under particularly violent discussion at the time. These courses were discontinued in 1979 for lack of attendance of the target group.

4.5 Exhibitions and Fairs

Representing the Nuclear Research Center at exhibitions is also one of the responsibilities of the Public Relations Department. The center participates in 3 - 5 exhibitions a year, whose impact is exclusively external in nature, apart, perhaps, from motivating the staff members involved. Fig. 15 shows one example: environmental measurement systems displayed by the Karlsruhe Nuclear Research Center at the 1986 ENVITEC international fair at Düsseldorf.

The success of exhibitions at fairs can be assessed on a largely objective basis, i.e., the reports by participants, which reflect both the general interest of visitors and the success achieved in technology transfer.

4.6 Guided Tours

Guided tours represent another major factor in external image building. The Center is visited by some 10,000 persons annually, who are guided by some 40 staff members from various institutes and departments on the basis of a highly standardized program. The standardization of the program, and the installation of permanent points to be visited within the units of KfK, was found to be necessary because of time consuming measures of physical security and radiation protection. Fig. 16 shows details of the program. First a film is run and an exhibition of the main activities of KfK is demonstrated; this is followed by a discussion, a round trip, and a tour usually of one technical object. The guides are recruited from among particularly interested scientific staff members, who undergo special didactic training. 80% of the visitors are primary and secondary school students (Fig. 17), most of them highly interested in the program. This makes guided tours an investment for the future.

Assessment of the impression visiting groups receive on their guided tours is largely objectified on the basis of questionnaires. An average of 40% of the visiting groups return the questionnaires, expressing unreservedly positive comments in some 70% of the cases. Frequent complaints are made, however, about the limitations, due to radiation protection and physical security, of possibilities to visit objects within radiation protection areas; even the permanent points visited on each guided tour at various institutes and departments are not considered to be adequate substitutes. This points to a clear conflict between security and safety requirements and the needs of public relations work. Points to be visited on guided tours therefore should be incorporated in the plant designs, if possible, as areas excluded from radiation protection control to which access is easy.

4.7 Nuclear Energy Information Staff

The Nuclear Energy Information Staff is an important instrument in improving the public acceptance of nuclear technology. It was set up in 1974, when the nuclear controversy was at its peak, and comprises some 30 staff members of the Center (Fig. 18). The members of the Nuclear Information Staff participate in public debates about nuclear energy, lecture to various groups of multipliers or at seminars organized by secondary schools, and write information brochures published by KfK on special topics under discussion. Fig. 19 is a list of the titles of those brochures and their circulations, with the added footnote that these publications are distributed mainly as single copies sent out on request. Fig. 20 gives you an impression of the presentation of these brochures.

As far as lecturing activities are concerned, effectiveness monitoring is based mainly on subjective assessment by the members of the Nuclear Energy Information Staff, apart from occasional reports about lecturing events. As far as publications are concerned, the demand for these brochures may be taken as a yardstick in objectifying impact research.

4.8 Corporate Displays and Publications

All displays and publications by the Nuclear Research Center, such as scientific reports, posters, slides, brochures, programs, memos, pamphlets, and even the car fleet, should bear uniform design features to achieve a recognizable corporate identity. This uniformity in presentation facilitates external identification and enhances awareness. Awareness is important, for there can be no appreciation without awareness. Also the internal identification of staff members with their institution is reinforced in this way, especially if that institution, like the Nuclear Research Center, is made up of a large number of scientific facilities with very many individual feelings of "institute identity." There is growing demand for these services by the Public Relations Department, but full acceptance of this standardization has not yet been achieved at the moment.

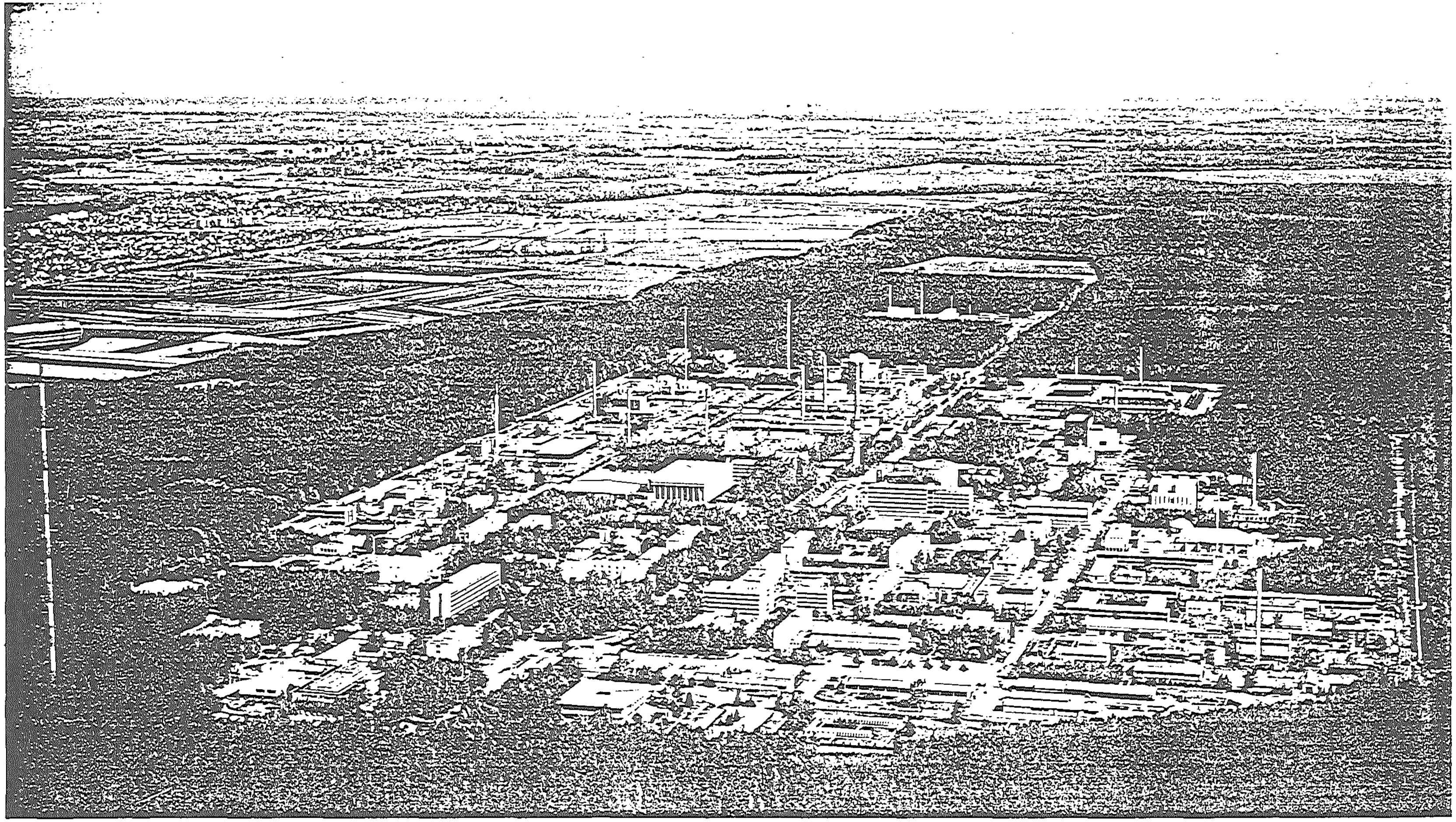
4.9 Conference Office

An important instrument in public relations work is the service offered to scientific meetings. The facilities of the Nuclear Research Center can be used as a venue for meetings of up to 500 participants. The Conference Office of the Public Relations Department organizes some 20 major events annually, each of which is attended by more than 100 persons. In addition, some 30 minor events with a total of approximately 1000 participants are organized. This service is provided in order to create a positive external impression through efficient conference organization and by taking good care of the participants in such meetings. The popularity of KfK as a venue for meetings is indicative of the success of these efforts.

5. Influencing Public Opinion

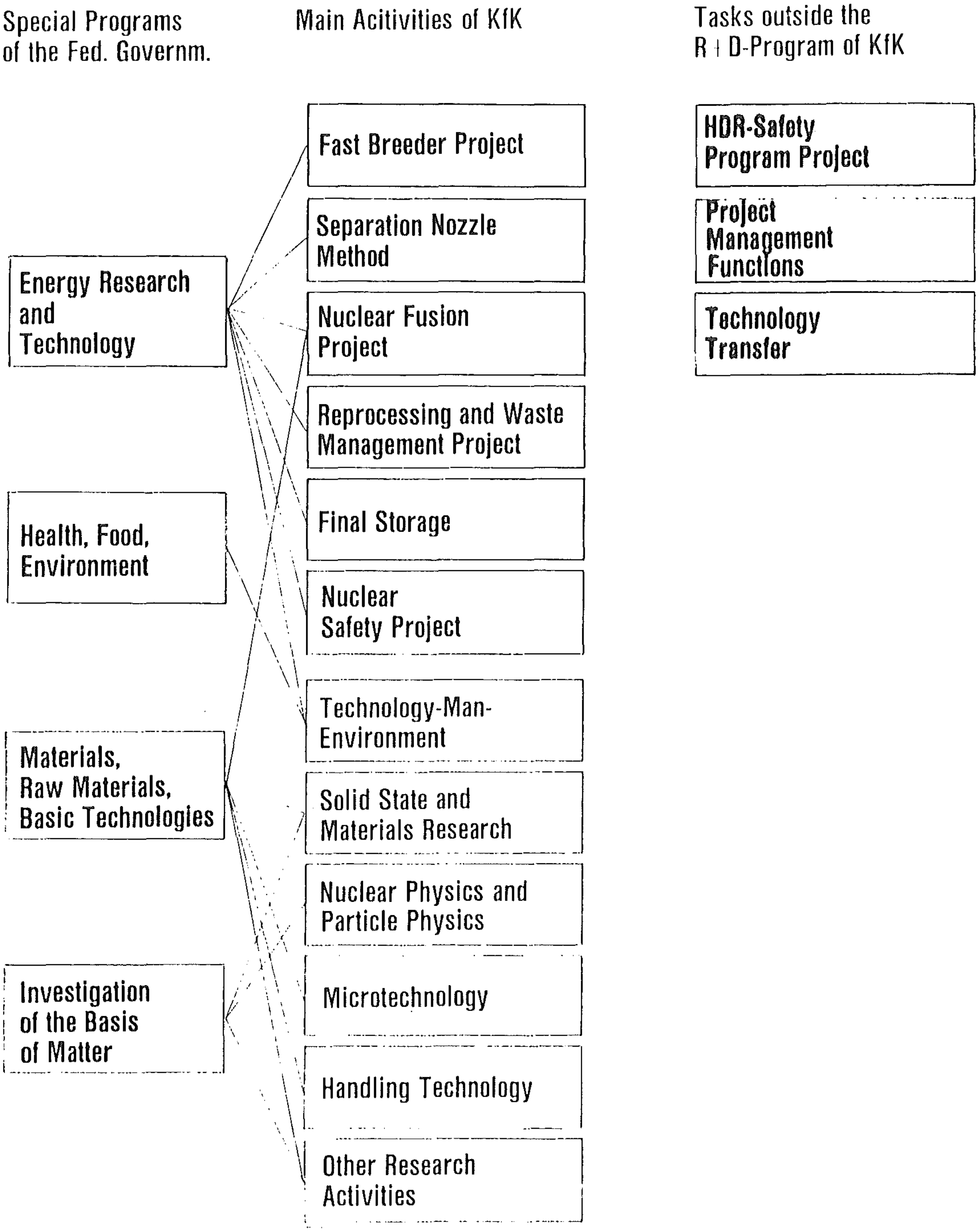
The influence exerted on public opinion by the public relations activities of an institution can be measured by representative polls. Fig. 21 shows an example. In a representative poll organized on a nation wide and a regional basis, we inquired about public awareness of the name of "Kernforschungszentrum Karlsruhe" and of the "KfK" acronym and also about the trend of public opinion. Even on a national basis, a surprising high score of 64% of public awareness was found. Regarding the trend of opinion, it is not the positive vote of 47% which is surprising, but rather the relatively low negative score of only 6% - compared, for example, with the 40 to 50% currently found for other industries in the focus of public interest. From a detailed evaluation of the results of the poll it can be concluded that these 6% are people more or less generally opposed to modern technology. Furthermore, it can be shown that the printed media represent the greatest source of public awareness.

Chernobyl had consequences not only on the public attitude towards nuclear power in Germany, but also on the organization of the Public Relations Department of the KfK, as far as emergencies are concerned. We have to admit that the event found us largely unprepared. As a consequence, we had to improvise our informing the news media, the public and the authorities. To avoid similar uncoordinated actions in the case of future events, we have set up an emergency committee in the meantime, which consists of members of the Executive Board, heads of relevant scientific, technical and administrative departments, and of the Public Relations Department. In case of an emergency, that committee will enlarge the Public Relations Department by delegating to it expert personnel from the institutes and by installing appropriate, prepared, technical means of communication. The production and the flow of information is directed to four clearly different groups: the media, the public, the staff and public authorities. We hope that it will not be necessary to put this plan into action.



Karlsruhe Nuclear Research Center

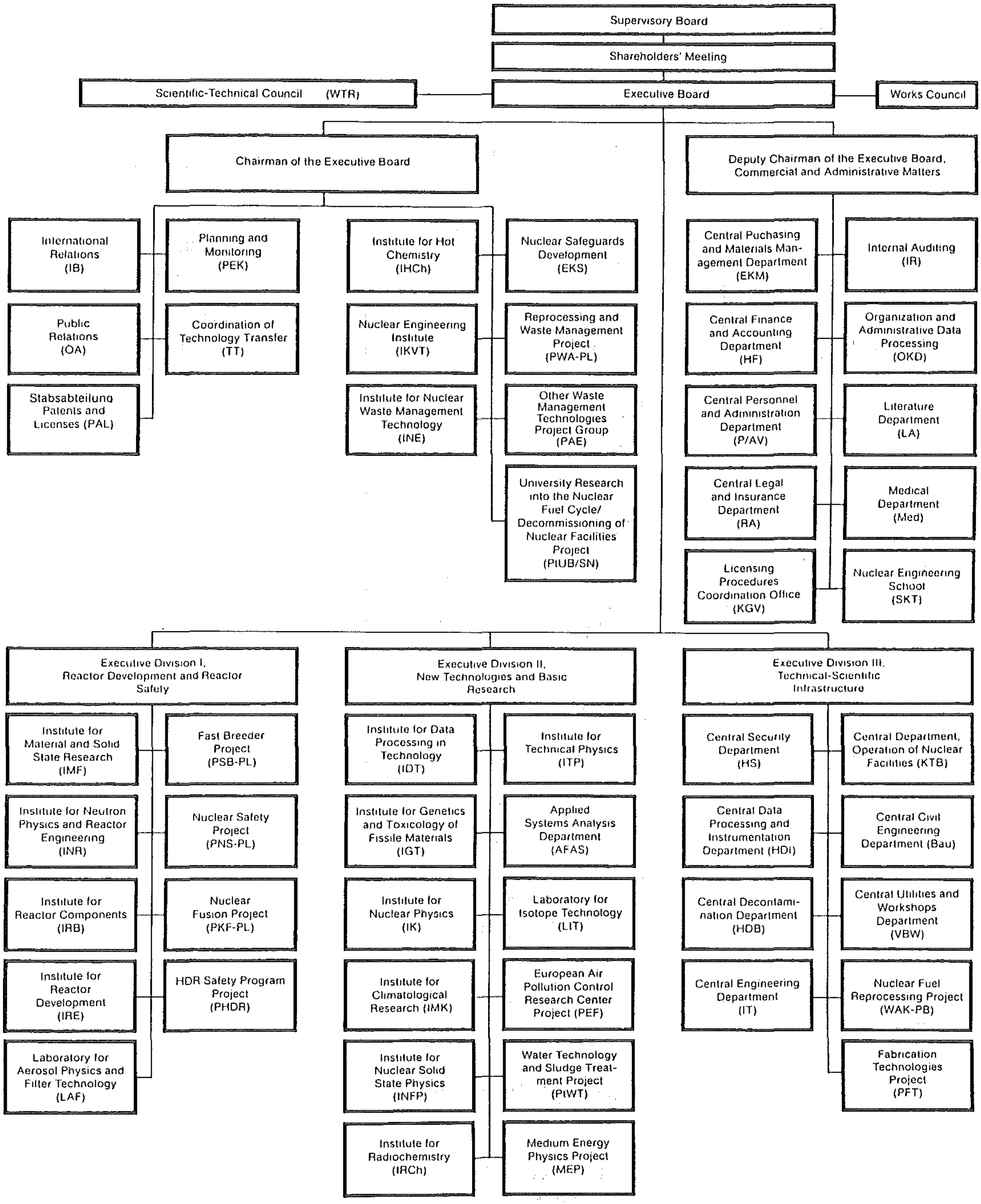
Fig. 1



KfK

Research- and Development-Program and other Scientific-Technical Activities of KfK in 1986

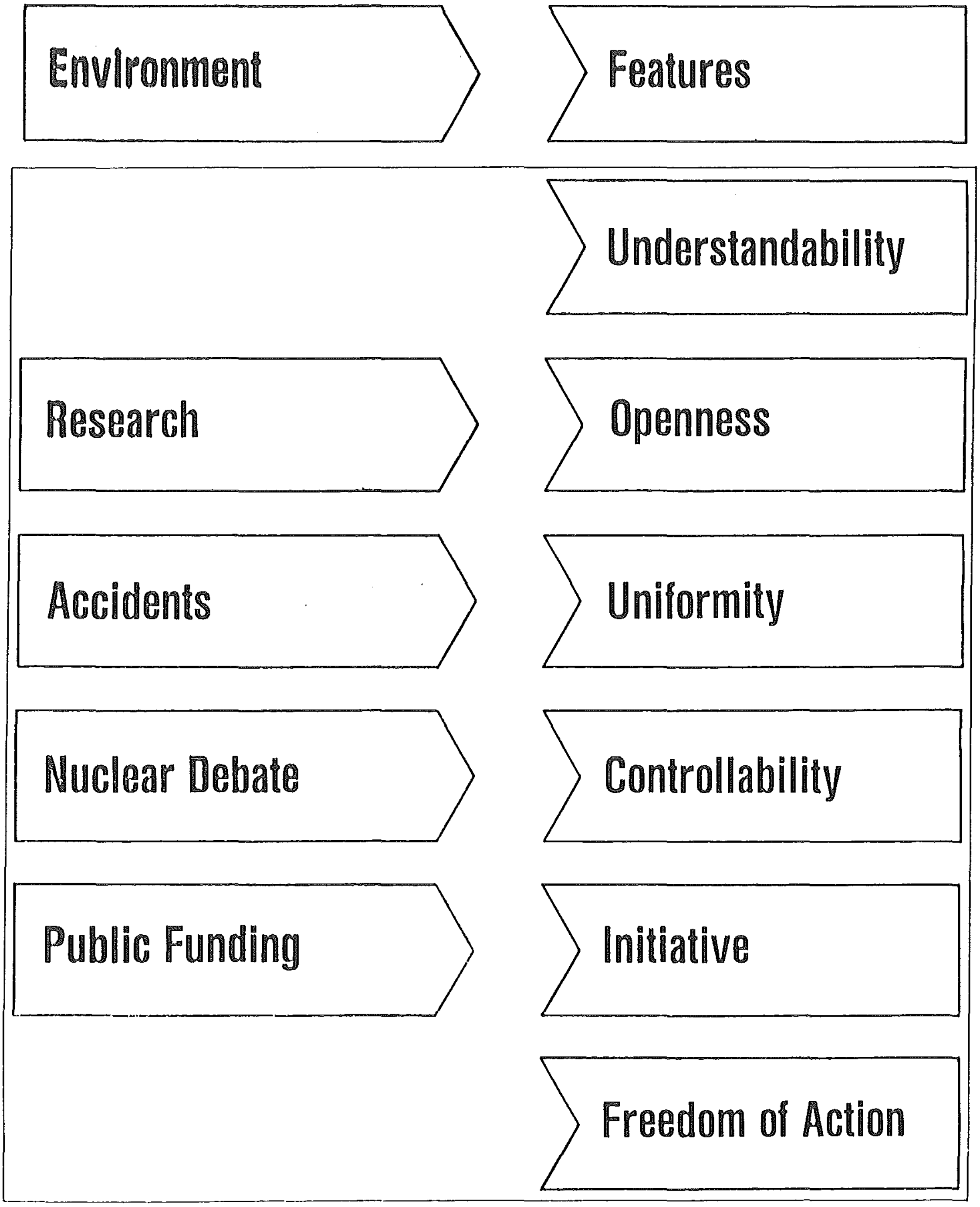
Fig. 2



KfK

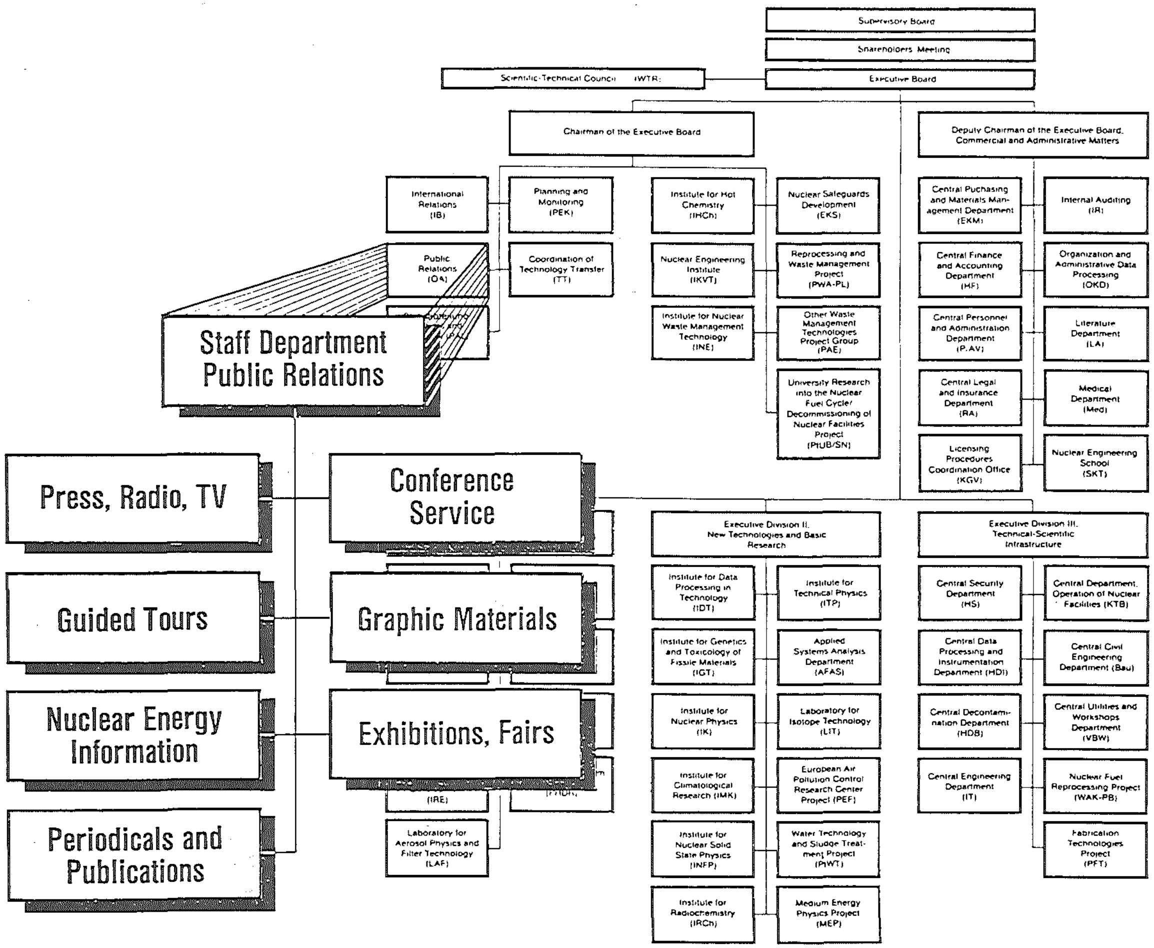
Organizational Structure

Fig. 3



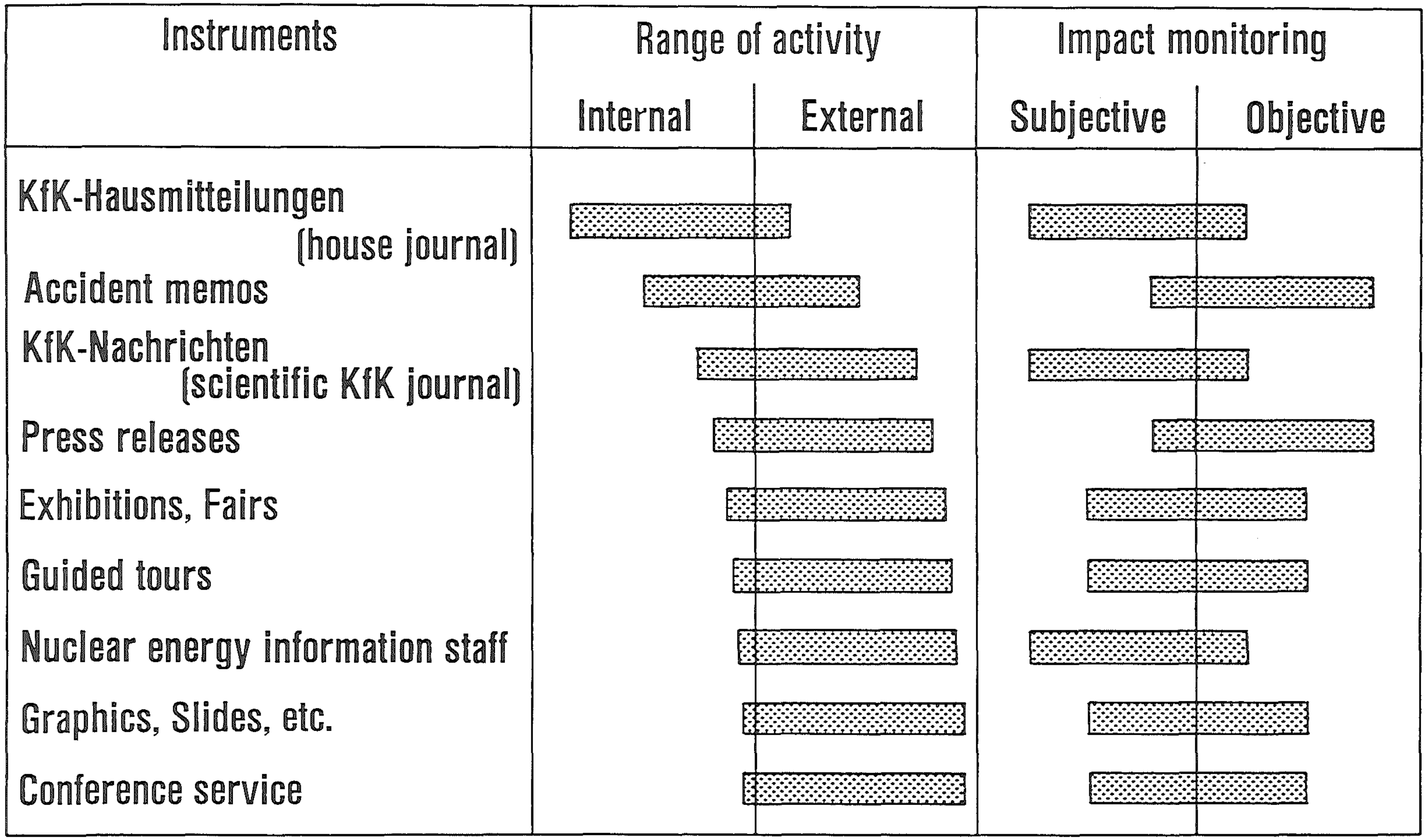
Environment and Features of the Public Relations of KfK

Fig. 4



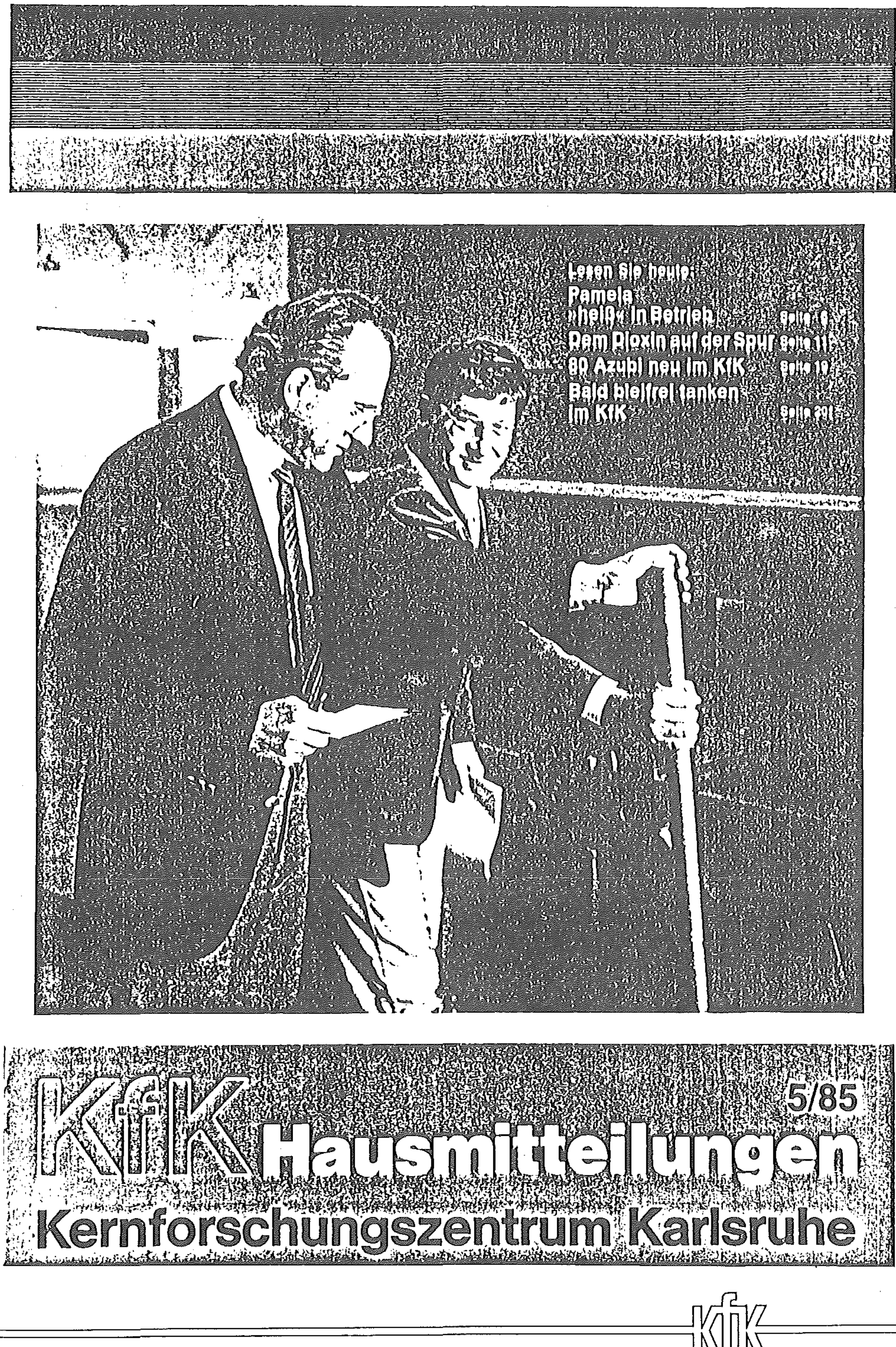
Public Relations at KfK

Fig. 5



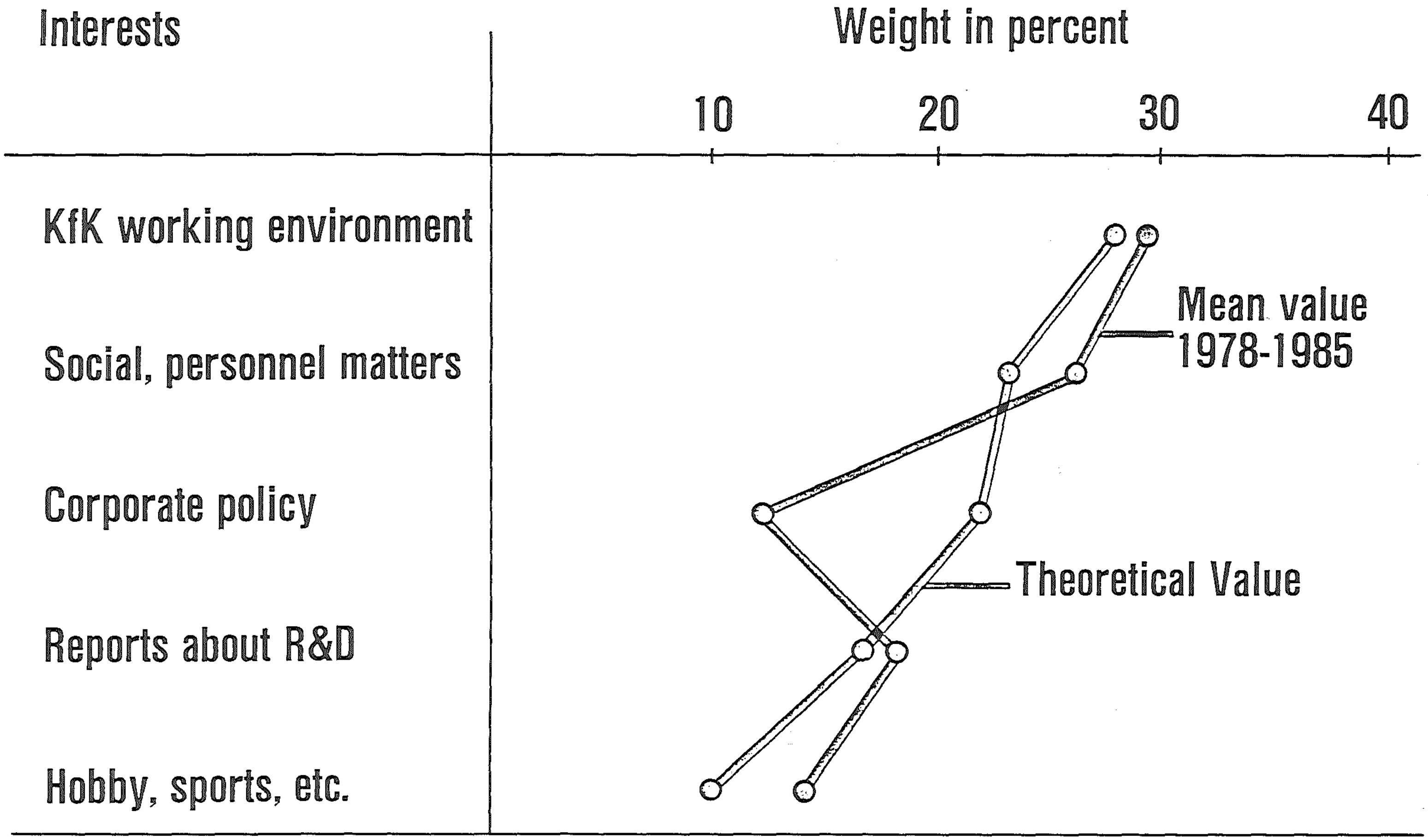
Instruments, range of activity and impact monitoring of public relations activities

Fig. 6



House journal

Fig. 7



KfK

Profile of interests covered in KfK-Hausmitteilungen (house journal)

Fig. 8

Interne Information

Kernforschungszentrum
Karlsruhe Vorstand

4.10.1985

Info Nr. 3/85

Am 3.10.1985 gegen 12.00 Uhr wurde ein im Technikum zur Komponentenerprobung (TEKO) beschäftigter Mitarbeiter beim Umgang mit einem Chemikalienbehälter im Lager für wiederverwertbare Chemieabfälle des KfK äußerlich mit Spuren von Plutonium und Americium kontaminiert. Die Kontamination wurde anschließend vollständig entfernt. Die am gleichen Tag durchgeführten Direktmessungen ergaben keinen Verdacht auf Inkorporation radioaktiver Stoffe. Ergänzende ausscheidungsanalytische Messungen werden durchgeführt.

Gegenwärtig wird untersucht, wie der kontaminierte Chemiekalienbehälter in das für nicht radioaktive Stoffe vorgesehene Chemielager gelangt ist. Die zuständigen Behörden wurden von dem Zwischenfall unterrichtet.

Kernforschungszentrum Karlsruhe GmbH · D-7500 Karlsruhe 1 · Postfach 3640 · Tel. (07247) 82 2861 · Fernschreiber 7826484

Accident memo

Fig. 9

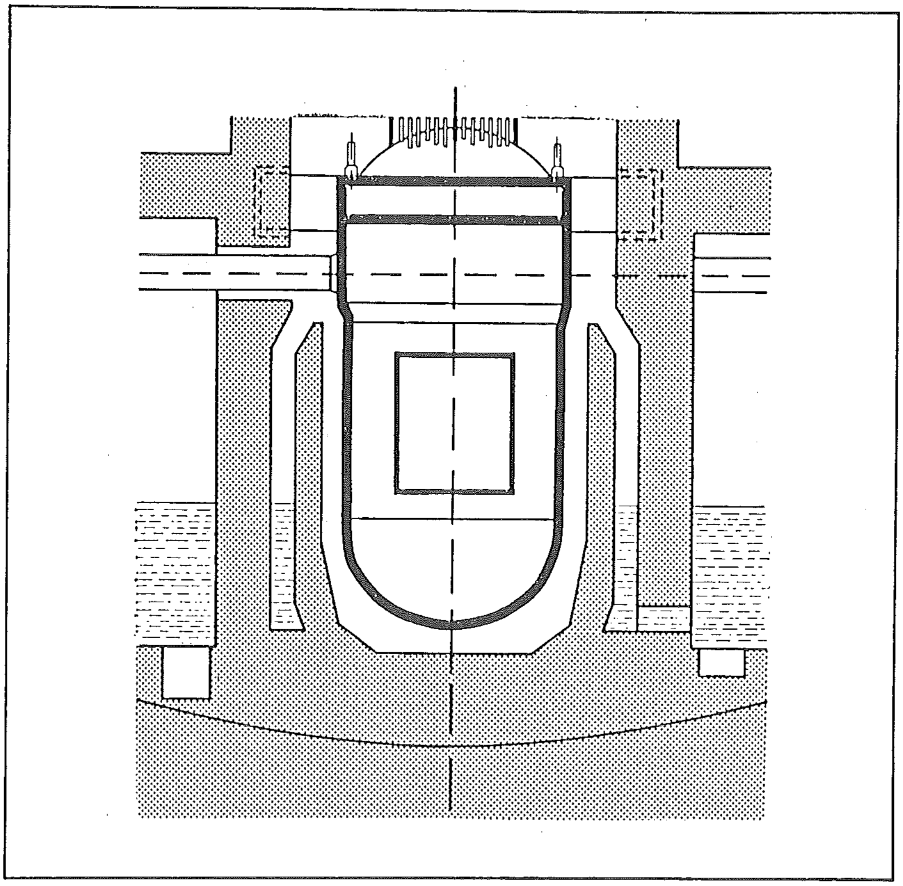
Year	Accident memos	Press clippings		
		Rate	Total	Negative
1978	10	5	51	25
1979	14	49	690	33
1980	17	36	620	2
1981	10	28	277	3
1982	5	19	94	0
1983	4	6	25	0
1984	4	46	183	0
1985	4	106	425	39

Average	9	37	296	13

KfK

Development of press coverage of accidents at KfK

Fig. 10



Jahrgang 17 1/85

KfK Nachrichten

Kernforschungszentrum Karlsruhe

KfK

Scientific Journal

Fig. 11

Presseinformation Kernforschungszentrum Karlsruhe

36/85

Seifenblase aus Baustahl

Vom Kernforschungszentrum Karlsruhe (KfK) wurde jetzt eine stählerne Kugelschale von rd. 1,3 Meter Durchmesser und einer Wandstärke von nur 1 Millimeter als Modellkörper für Schwingungsuntersuchungen entwickelt. Besonders bemerkenswert: Durch spanabhebende Herstellung konnten Formabweichungen von der Kugelgestalt der "stählernen Seifenblase" von weniger als 0,05% erreicht werden.

Der charakteristische, kugelförmige Reaktorsicherheitsbehälter ist bei Kernkraftwerken eine wichtige Barriere gegen die Freisetzung von Radionukliden. Für die Stabilität des Reaktorsicherheitsbehälters bei stoßartigen Belastungen, etwa durch Erdbeben, sind die in der Behälterwand auftretenden Schwingungen maßgebend. Die üblichen Rechenprogramme gehen dabei von einer idealen Kugelgestalt des Behälters aus. Im Institut für Reaktorentwicklung des Kernforschungszentrums soll dagegen jetzt quantitativ geklärt werden, welchen Einfluß die in der Praxis vorhandenen Abweichungen von der Kugelgestalt, etwa durch die Personen- und Materialschleusen oder die zahllosen Rohrleitungsdurchführungen in der Wand des Behälters auf sein Schwingungsverhalten haben. Besonders wichtig ist dabei die experimentelle Bestätigung der entwickelten Rechenmodelle. In-situ-Messungen der Schwingungsformen des Reaktorsicherheitsbehälters eines Kernkraftwerks mit seinen 56 Meter Durchmessern sind nur begrenzt möglich und für das theoretische Verständnis auch nur von begrenzter Aussagekraft.

Für die experimentellen Untersuchungen wurde daher ein maßstäblich verkleinertes Abbild des Sicherheitsbehälters von 1,3 Meter Durchmesser und einer Wandstärke von 1 Millimeter konzipiert: eine Seifenblase aus Stahl. Am Anfang der span-

./.

Nachdruck kostenlos Beleg erbeten

Kernforschungszentrum Karlsruhe GmbH, 7500 Karlsruhe 1, Postfach 3640, Telefon (07247) 822861, Fernschreiber 7826484

Press release

Fig. 12

Year	Press clippings			
	Total	Positiv	Neutral	Negative
1978	1881	766 41%	1052 56%	63 3%
1979	3755	705 19%	2940 78%	110 3%
1980	2913	874 30%	2004 69%	35 1%
1981	3058	702 23%	2331 76%	25 1%
1982	2126	862 40%	1165 54%	99 6%
1983	2527	838 33%	1620 64%	69 3%
1984	2709	841 31%	1840 68%	28 1%
1985	2902	1135 39%	1612 56%	155 5%

Average	2733	840 30%	1820 67%	73 3%

KfK

Press clippings 1978 - 1985

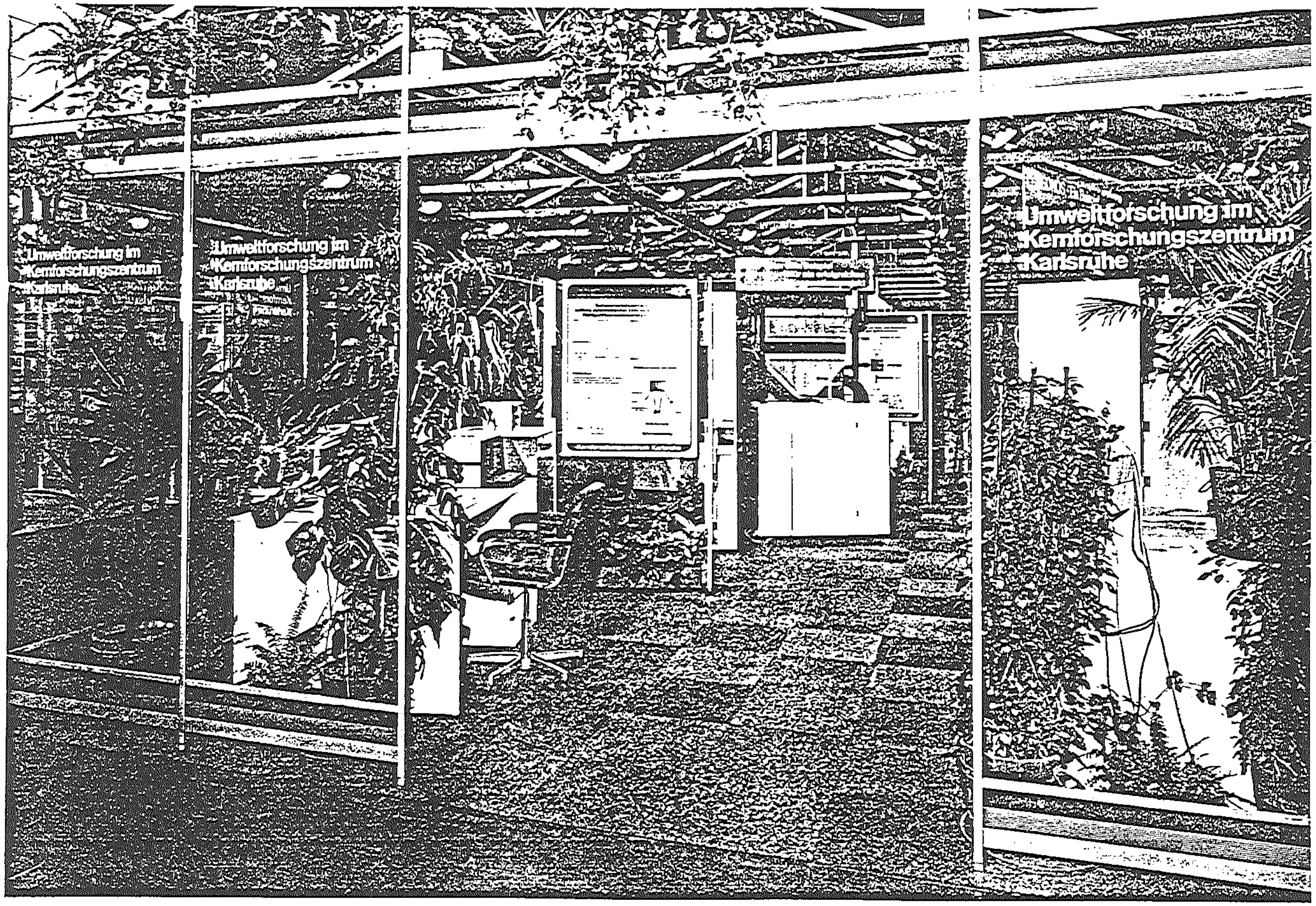
Fig. 13

Source		Total	Tendency		
			positive	neutral	negative
Press releases	46%	1331	867	449	15
Accident memos	15%	425	—	386	39
Other sources	39%	1146	268	777	101
Total	100%	2902	1135	1612	155

KfK

Press clippings covering KfK in 1985

Fig. 14



ENVITEC 1986

Fig. 15

Organization of Guided Tours

- Welcome by the guide of the tour
- Film and exhibition showing research priorities and main activities
- Discussion of questions raised by visitors
- Round trip and tour of one scientific institute

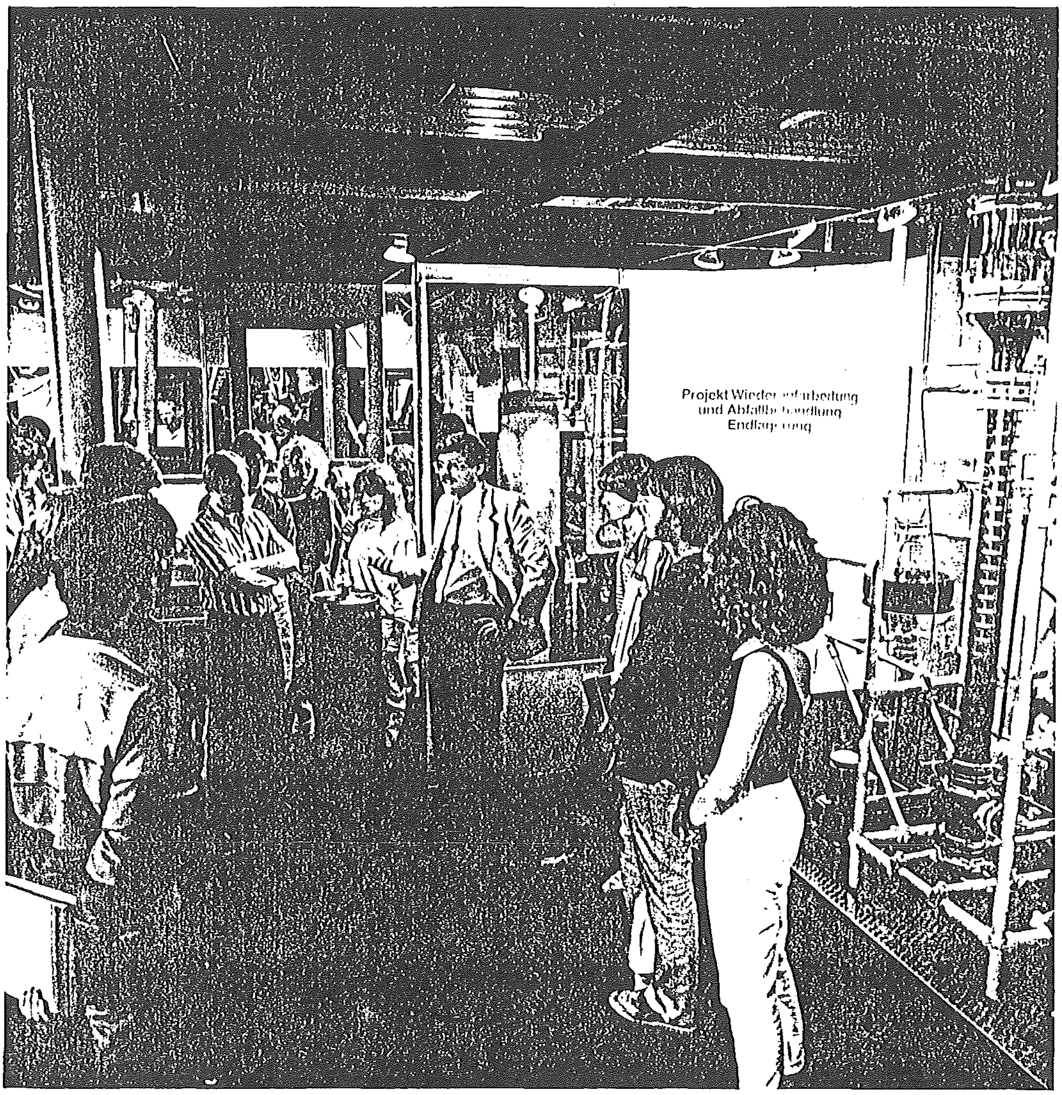
Guides

- 40 scientific and technical staff members from 20 institutes and departments
- Assignment and coordination by a member of the public relations staff
- University training and didactic skills
- Regular in-career training for public relations work
- Pay per guided tour

KfK

Aspects of organization of outside visits at the Karlsruhe Nuclear Research Center

Fig. 16



Students at KfK

Fig. 17

Duties

- Attendance at public events dealing with nuclear energy
- Courses for various groups of opinion leaders
- Seminars for high schools
- Brochures and pamphlets informing on important questions of nuclear energy

Structure

- 30 scientific and technical staff members from 20 institutes and departments
- Headed by a member of the public relations staff
- University background and didactic skills
- In-career training for public relations work
- Pay by assignment

KfK

Duties and structure of the nuclear energy information staff

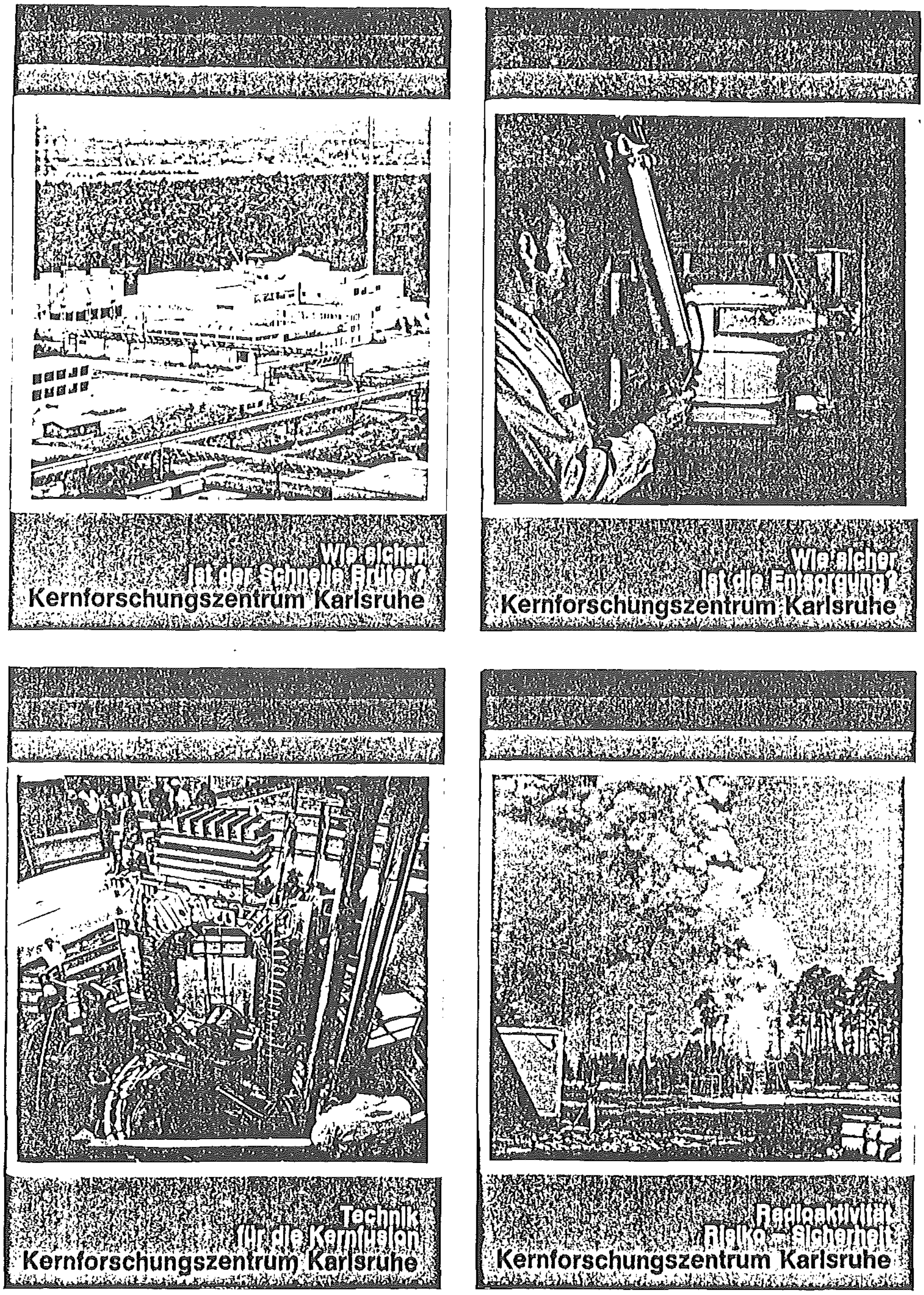
Fig. 18

Title	Publishing year	Distributed circulation 31.12.1985
How Safe is the Fast Breeder?	1978	131.800
Safety and Radiological Protection	1979	98.000
How Safe are the Back-End Fuel Cycle Services?	1980	107.000
Radioactivity — Risk — Safety	1982	76.300
Nuclear Fusion Technology	1985	7.000
Total		420.100

KfK

Brochures on special technical issues

Fig. 19



Brochures on current technical issues

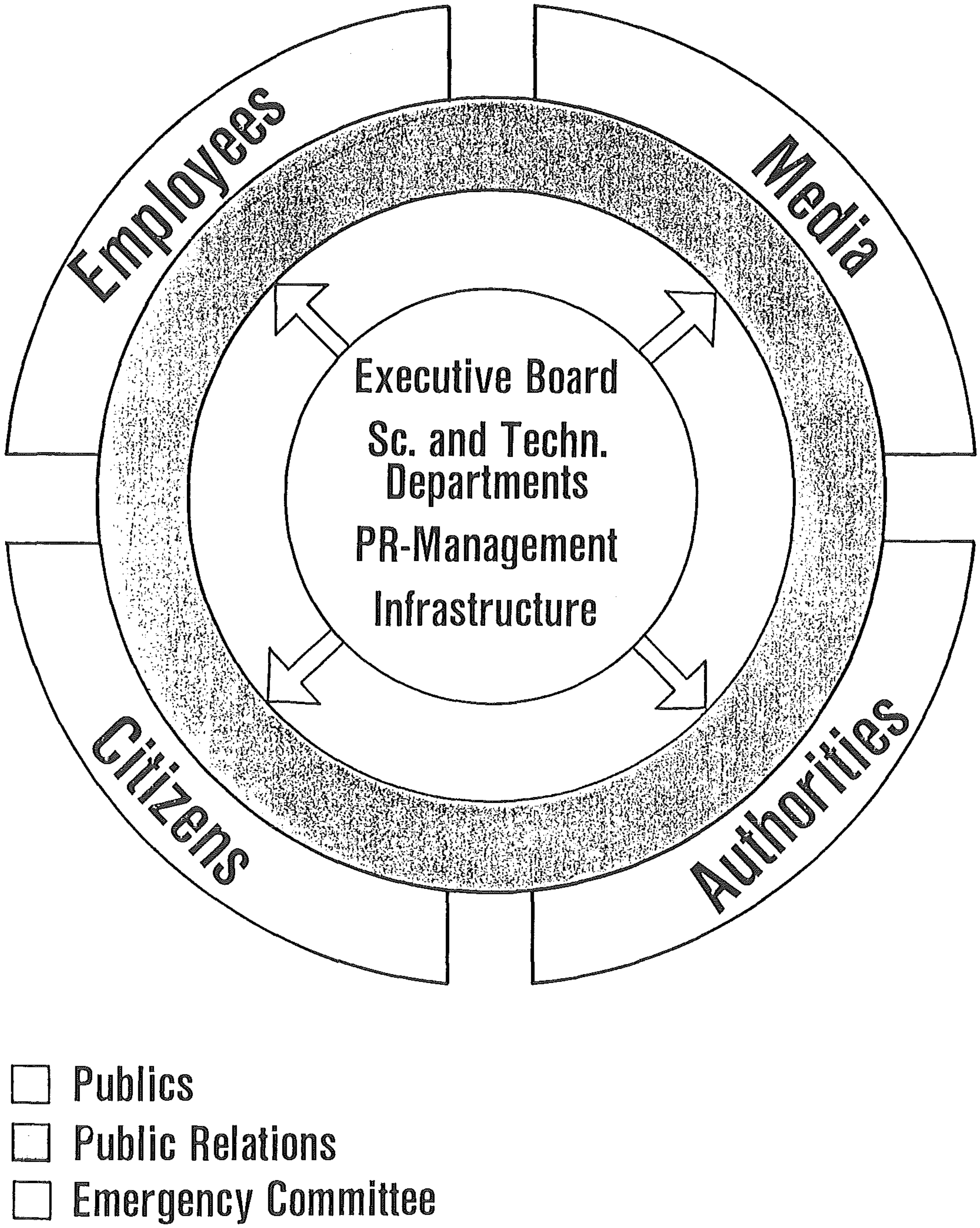
Fig. 20

	National	Regional
Public awareness		
Kernforschungszentrum Karlsruhe	64%	94%
KfK	7%	23%
Tendency of opinion		
positive	47%	58%
neutral	28%	25%
negative	6%	11%
No response	19%	6%

Source: Wickert-Institute Tübingen, January/February 1986

Kernforschungszentrum Karlsruhe: Public awareness and tendency of the public opinion

Fig. 21



Emergency Planning for Public Relations

Fig. 22

Horst Koppelstätter

Badische Neueste Nachrichten
D-7500 Karlsruhe

Experiences of a Newspaper Journalist with the Official Information Policy of Nuclear Facilities

1. The portrayal of the work and procedures of nuclear facilities by the press.

1.1 The newspaper and its readership

1.2 Editorial policy and decision mechanisms within a newspaper editorial department

2. The relationship between the press and technology in general

3. The experiences of a newspaper journalist in dealing with the press offices of nuclear facilities

3.1 A concrete example - cooperation between the Badische Neueste Nachrichten and the Karlsruhe Nuclear Research Centre

4. The demands of a newspaper journalist on the press spokesmen and operators of nuclear facilities

1. The portrayal of the work and procedures of nuclear facilities by the press

Even in the age of television, radio and the new media, daily newspapers still play a central role in the transmission of information in the Federal Republic of Germany. There are currently 1300 newspapers in the Federal Republic although, due to a progressive process of concentration, only 125 of these can still be termed independent. "Independent" means that a newspaper produces all sections of the paper itself, including the political pages, whilst the majority of papers confine themselves to local and regional news and take their political news from one of the big newspaper concerns.

The role of the regional press in the Federal Republic of Germany requires special emphasis, since it is of very great importance when it comes to conveying information. This is because West Germany has no "metropolis" like Paris, London or Rome. Bonn, admittedly, has been the seat of the Federal Government for almost four decades but Bonn has never assumed the function of a "central capital". This is why there is no "metropolitan press" in West Germany as is found in many other parts of the world.

1.1 The newspaper and its readership

The Badische Neueste Nachrichten in Karlsruhe is one of the big regional newspapers of the Federal Republic of Germany. With a daily circulation of some 180 000 copies, it covers a whole region some 130 kilometres long and 60 kilometres wide. The area which it takes in includes Federal Germany's largest nuclear research centre in Karlsruhe and the third largest nuclear power station in Philippsburg. The Badische

Neueste Nachrichten holds more or less a monopoly position in its circulation area, having no direct competition. For this reason alone, the daily newspaper on which I have worked for the last eight years constitutes one of the most important sources of information both for the population at large and for those in positions of responsibility in politics, industry, culture and the economy.

1.2 Editorial policy and decision mechanisms within a newspaper editorial department

What coverage then does the peaceful use of nuclear power receive in the daily newspaper? Before the rotary printing presses are switched on night after night and a couple of hundred thousand copies of the paper printed, it has been a long day for the editorial staff, in which countless items of news from all over the world have been competing with each other. What the news selection process actually involves is best illustrated with a figure: at times only five to ten percent of the news which reaches the editorial staff is passed on to the reader the next day. The remainder ends up in the wastepaper bin, since the space in a daily newspaper is limited.

It is thus obvious that a large number of decision mechanisms are involved when it comes to the nature, length and position of an article in the paper. This is far from being simply a question of which event is to be printed - the prime concern is the size of the articles and the items that are to feature on the front page the next day.

The central focus of these decisions is the editorial conference. Every afternoon all the heads of the editorial staff meet for this conference, chaired by the Editor-in-chief. Everyone reports on their most significant events of the day, and the provisional positioning and layout are then discussed and laid down - always providing that there are no new happenings on that particular day, in which case planning will have to start from scratch again.

The individual heads of the editorial staff more or less "fight" for space. Everyone naturally maintains that "his" or "her" happening is the most important of the day. The head of the foreign politics editorial staff, for instance, wants to see the latest news from Washington on the next day's front page, whilst the head of the sports staff regards the football match as the prime event of the day, and the economic staff want to be allocated space right at the front for Daimler-Benz's balance sheet figures. It is then difficult for me, as "regional news" editor to come by space for topics such as new research results from the nuclear research centre or the reliable operation of the Philippsburg nuclear power station. Experience has, admittedly, shown that the more specialist knowledge a journalist has about a specific topic, the more likely he is to be able to convince colleagues on the editorial staff of the importance of the subject.

2. The relationship between the press and technology in general

A number of remarks on the relationship between technology and the press in Federal Germany are called for at this point. First of all, it is important not to be under any illusions. Only very few journalists on daily papers and illustrated weeklies were great experts at school when it came to mathematics, physics and chemistry. Concepts such as kilowatts and kilowatt hours, or activity and dosage, then very readily become mixed up. And kilowatts or horsepower are, all the same, still concepts which occur in everyday life. Everything else which goes beyond domestic and automobile technology is by and large incomprehensible to the majority of the population. This explains why technology and its fringe areas frequently receive insufficient coverage in the newspaper.

This anomalous state of affairs has doubtless also developed on account of the need felt by newspapers to be highly topical, often believing that they can only print "new" reports. They forget, however, that things which have perhaps been common knowledge to technical experts for years are experienced by the reader as being something new and worth knowing.

This is why, when a journalist gives an account of technical processes, he repeatedly has to provide a vivid explanation for the layman of details which have been familiar to the experts for a long time. What use is even the most brilliant of reports if the reader cannot understand it?

Here is an example taken from a newspaper of how to explain to the reader in vivid terms what an atom really is: "an atom sitting at the end of an eyelash would be like a greenfly in Munich with a 130 kilometre motorway stretching out in front of it, so inconceivably small is it. Scientists thus save themselves the trouble of working out all the noughts after the decimal point (0.0000....) and say that "in terms of the theory of gas kinetics, the diameter of an atom is ten to the minus seven millimetres. This means that it takes ten million atoms lined up side by side to produce a row one millimetre in length.

All materials are made up of atoms - ships, shoes and paint. Most atoms are content with their fate and behave calmly. Scientists call these stable atoms. Others are restless and will not give any peace until they have changed into a different atom. One atom of this type is radium, which changes into lead."

So much for this extract from a vividly comprehensible newspaper article. An expert may well laugh at it, but it must not be forgotten that reading a newspaper is no substitute for five years at Technical University. The reader has at least obtained a small degree of insight into the world in which he lives.

As a rule, an editor will not be able to assume too much fundamental knowledge on the part of his readers, since the increasing specialisation in the world of work (and at school) has largely led to the demise of the polyhistor and the man of great learning. Let us come back to the ominous kilowatt again. There would be little point in providing an explanation of the kilowatt. What use is it to the reader to learn that a kilowatt is the equivalent of 1.36 horsepower. He has a sufficiently good conception of a kilowatt from the fact that an oven uses one kilowatt and a light bulb 60 Watts.

In contrast to the Federal Republic of Germany, science and technology in the United States have long been integrated into popular usage in what is frequently a very informal approach. A belief in progress and the question of the economic benefit for the individual have secured popular science a broad readership in the United States. In Germany, however, the links between the press and technology are still very loose in a large number of cases. There are relatively few technical journalists. These then sprinkle the whole of Federal Germany with news services so that the articles also suffer from a monotonous uniformity throughout the country. People from the technical world frequently make the suggestion that the daily press should call upon the staff of the technical journals more frequently. The engineers naturally overlook the fact that only very few technical journalists have become familiar with the day-to-day journalism of a newspaper in the course of their career - as a rule they come from their technical discipline and not from a newspaper.

In many cases, these technical journalists will give one hundred percent accuracy precedence over readability. Technical experts just aren't prepared to sacrifice a nuance for the sake of the general comprehensibility of an article. In my opinion, a ninety-five percent correct article with one hundred thousand readers is at times better than a one hundred percent article with only two thousand readers. Of course, the journalist must not misrepresent the technical problem in order to make his writing more attractive. He is not allowed to serve up any hollow sensations but may to simplify the process, just as he would simplify, condense and clarify the speakers' arguments at a meeting of the local allotment gardeners.

On the other hand, however, there is confusion in a large number of newspaper publishers' as to the section in which technical problems should be covered - in the economic section, the feature section, on one of the political pages or in a special scientific column. Here again, direct contact between the press office of nuclear power stations and the editors proves very helpful. This makes it possible to prevent good articles from getting caught up a the fatal process of being passed from editor to editor and finally ending up in the waste paper bin.

3. The experiences of a newspaper journalist in dealing with the press offices of nuclear facilities

One of the biggest problems for a newspaper journalist is to communicate highly specialist statements about technical matters to the reader in comprehensible form. This calls for a great deal of initiative on the part of the journalist and also for total confidence in the informant at the nuclear facility, i.e. the press spokesman.

In the rush with which the notification of an incident, for example, has to be assessed and processed, there is no time to call upon independent experts. It is the assessment of the consequences of an incident, however, which largely determines whether the announcement is taken up in the paper. If it is to be taken up, the question is then whether there should be a big report of the incident on the front page or a small article in the regional, or even local, section.

The editor must, therefore, be able to rely to a large extent on the press spokesman's assessment. If, however, it subsequently emerges - even just on one single occasion - that the press spokesman has deliberately given incorrect information or even withheld information, then the basis of cooperation that has been built up over many years is shattered overnight.

The extent to which general topics relating to atomic energy, such as nuclear safety, the background to research projects, developments and trends in a nuclear research centre, are able to establish themselves within a newspaper editorial department depends on how well the competent editor is informed and on his basic attitude to the peaceful use of atomic power.

There are much more rewarding subjects for a newspaper editor, which are much easier to write about, are more fun and cause a greater stir amongst the public and within the editorial department than reports on the routine in nuclear research or in a nuclear power station. The way in which news from a nuclear power station or research centre is prepared thus plays a big role.

One very important point for an editor on a daily newspaper is that he should have means of further educating himself in specialist fields such as nuclear energy. In my opinion, nuclear power stations and nuclear research centres in the Federal Republic of Germany do not do enough here. The Deutsche Atomforum (German Atomic Forum) is alone in holding seminars for journalists once a year, in which technical matters are clearly explained, often in-situ, in a way which is comprehensible to non-scientists as well.

It is my opinion that the less knowledgeable journalists and readers are about a particular specialist area, like nuclear energy, the more readily they will let themselves be influenced by the political agitation of the opponents. Now, radiation cannot be seen, smelt or touched. Rumours about dangers and problems thus spread quickly and putting these straight with factual information is a very difficult process. Allow me to draw a comparison: if someone stands up in a fully occupied cinema and shouts "fire, fire", people will quickly start to panic. It will then be difficult to make the people who are pushing to get out understand that it was simply a false alarm.

One big danger when giving an account of the use of nuclear power is that of getting things out of proportion. If it is not possible to report continuously on the normal state of research in a medium such as the daily newspaper or the television then ultimately it will be only the negative news, i.e. the incidents, which will feature in the news of the day.

It is then no longer possible to give an objective account of the facts. This has made it clear just how decisive the good work of a press spokesman at a nuclear research centre or nuclear power station is.

3.1 A concrete example - cooperation between the Badische Neueste Nachrichten and the Karlsruhe Nuclear Research Centre

To take an example from real life: the Karlsruhe Nuclear Research Centre issues a large number of press releases over the year, all of which pass over my desk. Although I have been concerned with the peaceful use of atomic energy for many years, the percentage of information that I directly understand and am thus able to reword in articles averages 20% or less per press release. It can be assumed that if these statements were to be printed as they stand, as is the case in a number of small newspapers, the readers would be in a similar situation. They see the name "Nuclear Research Centre" but can do precious little with the information that follows. Viewed in this way, the high print figures that official institutions such as the nuclear research centre like to publish are frequently misleading when it comes to the actual information value.

The reason for what are frequently difficult to understand press releases lies in the fact that this information is also supplied to technical journals and technical editors on other journals where the information content is, of course, allowed to be of a considerably more technical nature.

As a rule, it is only possible to use press releases from the nuclear research centre after consultation with the press spokesman in order to bring the contents into line with a newspaper. This functions very well in Karlsruhe - indeed, in an exemplary manner. The staff of the public relations division provide every conceivable assistance for journalists seeking information. This has, for instance, developed to the point where I can ring the press spokesman at home at any time and receive detailed information from him. In the further course of his work too, he will put me in contact with anyone I wish to speak to, right up to the chairman of the board of directors. A firm relationship of trust has been built up over the years, with each side being able to rely totally on the other. A situation of this kind is naturally very much a question of the personalities involved.

Just how good the relationship between the press and nuclear power stations really is cannot be read off from the number of press releases printed but only emerges at a time of crisis. Such a case occurred - admittedly only as a side issue in the Federal Republic of Germany - following the accident at the Chernobyl reactor.

I shall outline a number of impressions of my experiences as a newspaper editor attempting to obtain information following the accident. The experts at the nuclear research centre were initially unwilling to make any statements as to the extent and background of Chernobyl since they had too little concrete information. Yet the need for information within the newspaper's editorial department, and amongst the public as well, was enormous. It was high time to reduce the anxiety prevailing amongst the population with concentrated, objective explanations.

The basically well-equipped press department of the nuclear research centre was obviously completely overwhelmed by the flood of inquiries from the media and also from the public. This meant that it was impossible for me, as an editor who had been in close contact with the nuclear research centre for many years, even to obtain short definitions of the chief concepts such as iodine 137, strontium, half-life and similar. This would have been essential for the reader as an explanation right at the outset of the discussion. The press office's telephone lines were so frequently engaged that it was virtually impossible to reach an expert capable of explaining complex technical matters. The information shortfall on the part of the journalist then became an information shortfall on the part of the reader. The case of Chernobyl showed clearly that the press offices of nuclear power stations and nuclear research centres are not prepared for crises. In such a case it would not really be enough simply to react, i.e. to answer inquiries. Instead, there should be a team of experts available to come forward of its own accord and make a contribution towards elucidating matters in concrete terms. Breakdowns of this nature at a time when all discussions are suddenly centred around a single topic destroy the positive policy of information that has been built up over many years and nurture (in many cases incorrectly so) the doubts of critics and sceptics of the peaceful use of nuclear energy.

4. The demands of a newspaper journalist on the press spokesmen and operators of nuclear facilities

On the basis of my experience in daily dealings with information from nuclear facilities I would place the following demands on the operators of nuclear facilities in my capacity as a newspaper editor:

4.1 Information from a research centre or a nuclear power station must be readily comprehensible to the editor.

4.2 A relationship of mutual trust must be built up between editorial staff and the press office.

4.3 Information must be passed on quickly, i.e. whilst it is still highly topical.

4.4 The information policy of nuclear facilities must be one of complete openness vis-à-vis the public. Only an offensive strategy will lead to acceptance by the public over the long term.

4.5 It is frequently necessary to find a compromise between technical precision and intelligibility to the average newspaper reader.

4.6 There must be a continuous flow of information from a nuclear research centre and from nuclear power stations, and not simply information when problems arise.

4.7 The representatives of the interests of nuclear facility operators must take pains to ensure that journalists are provided with further education in this specialist area in seminars, lectures and printed material.

4.8 Press offices must also be prepared for crises, i.e. sufficient personnel must be available to cope with a large flood of journalists seeking information.

BATAN ACTIVITIES IN RADWASTE MANAGEMENT *)

by

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BATAN ACTIVITIES IN WASTE MANAGEMENT *)

1. INTRODUCTION

The basic objective of radioactive waste management at BATAN's Nuclear Installation is to treat the waste in such a way that the release of an unacceptable amount of radioactivity into the environment could be prevented. So any discharge of effluent radioactive to the environment is low as reasonably achievable, taking into account economic, social, and psychological factors.

Due to such reason all radioactive waste should be processed. In order to establish a viable waste management system, and to meet the goals and needs for the future nuclear science and technology development in Indonesia, a range of policy and technological options should be considered.

The options presented here are directed for short and long term needs, and are based on existing technology, demonstrated as the safest, most effective and efficient managament method.
Short term options include identification and development of improved treatment methods which can reduce volume, characterization of the treated waste for safety store in intermediate storage facilities, pending final disposal.
These options could be implemented within five years. The long term options are ultimate disposal options and directed for the final goal of workable and effective waste management system. Implementation of these options may require regulatory action and legislative approval for its initiation and operation.

2. THE ROUTINE OPERATION

The first reactor, TRIGA MARK II 250 Kw, was commisioned in 1965. In 1971 the power was upgraded to 1000 Kw for routine production of radioisotopes. The radioactive - waste produced from the processing facility which mostly contain short lived radionuclide is collected in the hold-up tank for further decay down to insignificant activity, then further diluted and dispersed in the river.

At the Nuclear Industrial Complexes, Puspiptek, Serpong, the radioactive liquid wastes that will be treated in RWMS (Rad. Waste Management Station) should have criterias as follows :

- Activity which could be treated $10^{-6} < A < 2.10^{-2}$ Ci/m^3
- Non corrosive and without organic materials
- pH between 7 - 9

2. 1. Sources of Radioactive Waste.

In a reactor building the liquid wastes are divided into two categories, low active and high active liquid waste :

- Low active liquid waste, having the activity of 10^{-6} to 10^{-2} Ci/m^3.
- High active liquid waste, having the activity of 10^{-2} to 10^{2} Ci/m^3.

The system or components from which the radioactive liquid waste originated, are from : pool drainage, shower and wash water, and ventilation system ; and the high active liquid waste are from : resin flushing, power-ramp test, and decontamination of isotope box.

The spent resin coming from the water purification system will be handled as semi liquid waste. Radioactive solid waste consists of used reactor component, capsules, filters, etc.

From radioisotope installation the radioactive wastes are classified as follows :

- The socalled "large quantity", with a dose rate greater than 1000 mR/h at the surface. At the time they are packaged, they contain mixed fission products.
- The socaled "small quantity", with a dose rate of less than 1000 mR/h at the surface they contain solid materials and solidified liquid wastes from the processing hot cell.

The radioactive liquid wastes that comes from fuel element production installation are mostly contaminated with chemical wastes in which the uranium content is very low and so is the activity of the liquid.
The solid wastes consisting contaminated linnen, paper, filters, overshoes, gloves, etc. are collected in a plastic bag, put into 100 liter drums and sent to RWMS.

2. 2. Treatment of Liquid Waste.

All radioactive wastes originated from laboratory installation in Nuclear Industrial Research and Development Complexes are treated centrally in RWMS, except the very high active waste are treated "in situ" in the hot cell by solidification either with cement or epoxy.

There are two main objectives in applying the general principle of concentrating and conditioning radioactive wastes, i.e. :

a) to enable large volume of liquid to be decontaminated by evaporation and the distilate which is then discharged in accordance with relevant regulation or re-used.

b) to convert and/or to concentrate the radioactive-waste into a minimum solid volume.

Many factors have been considered in selecting the most suitable and economic treatment plant applicable to liquid wastes in Serpong Nuclear Installation , for example :

- quantity of liquid expected by each laboratory
- possibility of recycling of treated liquid
- presence of particulate material and organic compound
- chemical composition of the solution, especially salt content and corrosive materials
- pH
- gross activity and radionuclide composition
- permissable discharge limit
- criteria such as reliability and maintainability of plant, exposure of personnel.

The wastes are collected from each installation and transported to RWMS by waste transporter, that is tanker trailer for the liquid waste or truck with bin for the solid wastes.

The liquid wastes containing non organic subtances and non corrosive chemical are collected and mixed together in the head tanks which have a capacity of 4 x 50 m^3.

Since the volume of these liquid wastes are expected to be large, processing option is based on volume reduction by evaporation. Evaporation process has been selected - by assessment of safety, high decontamination factor and cost effectiveness of the operation. The evaporator is a thermosiphon type, automatically operated, equiped with indicators and recorders necessary for system surveilance, push bottoms actuators and remote controlled valves, warning indicator for indicating any exceeded threshold or incidents that could be occured during operation.

2.3. Conditioning Process.

The concentrated liquid from the evaporation process is, then, pumped into immobilization unit for further conditioning with cement in steel lined container called "shell". This unit are installed in the hot cell. The operation is automatic and remotely observed through a shielded glass window. Cementation is not only selected as the simlest and the most adequate method for conditioning of low and medium level semiliquid wastes, but also the chemical and physical properties of cement are well known. Besides, cement is also readily available and comparatively inexpensive.

However, knowledge of the effect of mixing cement with radioactive wastes is still limited. To support - routine work R & D has been programmed to optimize cement waste formulation. The embeded product contained in the shell is covered by lid and sealed. Then, it is transfered into the interim storage after drying. These shells ensure biological shielding enabling a contact dose rate less than 200 mRem/h.

2. 4. Treatment of Solid Wastes.

The radioactive solid wastes are sorted as compactible and non compactible wastes. To minimize the risk of dispersion of contamination, and in order to mitigate exessive radiation exposure by air borne radioactivity from the contaminated dust, sorting gloves should be provided during handling. The compactible solid wastes are put into 100 liter steel drums and compacted one by one into 200 liter drums by means of 600 KN hydraulic press. The 200 liter drums can accomodate 5 compacted 100 liter drum. To avoid dispersal of contaminants during the operation the press is put in a ventilated - hood, connected to the off-gas system. The compacted wastes are then conditioned with cement slurry. The on compactible solid wastes will be directed in 200 liter drums on a vibrating table.

3. INTERIM STORAGE.

The mode of ultimate disposal of embedded wastes is not decided yet due to unsufficient data concerning the characteristics of embedded wastes and also the interaction of the wastes with the environment. These datas are required for designing the repository of the ultimate disposal. The engineered storage was planned to built at Serpong to store the processed wastes for an interim period.

The period of interim storage was planned for 5 - 10 years. In this period of time it is expected to gain sufficient data from R & D programmes, as mentioned before, leading into a decision in building the shallow ground repository used for ultimate disposal for the low and medium level embedded wastes. The interim storage at the Nuclear Industrial Research and Development Complexes, Puspiptek , Serpong had been constructed with a module type design.

One module having a capacity of 500 shells and 1500 drums, is designed for maximum dose rate of 2,5 mRem/h in the unloading and handling room, of 10 mRem/h and 0,7 mRem / h in storage room and inside the building respectively.

4. CONTROL OF THE ENVIRONMENT

Based on the recommendation of the International Commission on Radiological Protection (ICRP), our national regulation states that radioactive materials should be prevented being released into the environment. If it follows the basic principles of radiation protection, public exposure to radiation could be kept as low as reasonably achievable.

Based on the through knowledge of how radioactivity behaves, the system of monitoring environment either on or off site includes :

- Operating a network of control points to measure the radioactivity throughout the transfer chain : air, ground water, and food.
- Routine monitoring and checking the level of seepage water and ground water table.

Measuring the natural radioactivity either on or off site had been performed, and the data obtained will be used as reference when the facilities will be in operation in 1987. The on-site monitoring will be backed up by appropriate environmental monitoring in accordance with IAEA Safety Series No. 41, "Objective and Design of Environmental Monitoring Programmes for Radioactive Contaminants". The monitoring process has been designed to give information about the sources and characteristics of radionuclide and to provide adequate information to demonstrate in compliance with authorization.

For gaseous effluent, two types of measurement will be provided, i.e. :

- Continuous measurement at fixed location where radiation levels are mentioned continuously and recorded remotly using Reuter Stokes Centri 1012 Radiation Monitoring System with 10 station.
- Periodic measurement as mentioned above by sampling of transfer chain.

5. RESEARCH AND DEVELOPMENT PROGRAMME.

To support the options, BATAN is currently enganged in a comprehensive programme of Research and Development directed from Radioactive Waste Management Technology Centre of Nuclear Industrial Research and Development Complexes, Puspiptek, Serpong. The objectives of the programme are :

a) To assess the environmental and safety aspects of the radioactive waste disposal concept.

b) To develop technology for volume reduction, immobilization, storage, and disposal at shallow ground repository.

c) To develop the analysis and characterization of embedded wastes.

d) To study the interaction of embedded wastes with the environment, and characteristics of different clay (argillaceous materials) as the natural barrier.

e) To establish the requirement, equipment, and procedures for site characterization and selection.

f) To develop public acceptance to support the concept.

The concept of R & D programme are focussed on disposal of immobilized low and medium level radioactive wastes on shallow ground repositories provided with engineered barriers. The wastes which to be disposed off are solid or solidified, which are immobilized in steel lined con - crete containers the socalled "shells". The containers , then, will be put into a concrete cell acting as enginee- red barrier which is built in the subsurface of the ground surrounded by argillaceous materials as the natural bar - rier. The only feasible way that radioactive species could return to the biosphere is by ground water breaching the containment, dissolves the waste form and transports the dissolved radionuclide through the geosphere back to the surface. To minimize ground water flow to and from the waste form and to prevent the movement of the radionucli- de species that dissolved in the ground water the dispo - sal system therefore will be a comprehend system of engi- neered barrier.

The major components of the R & D are :

- Characterization of the embedded waste.
- Characterization of the argillaceous materials used as natural barrier.
- Geotechnical engineering and geosciences
- Environmental and safety assessment.

5. 1. Characterization of the Embedded Waste.

The objectives of this component are :

- To develop know-how and skill of analyzing and cha - racterization of the embedded wastes in order to meet the requirement for final disposal in shallow ground repository.

- To ensure satisfactory of safe containment by performance, providing additional barrier to radionuclide migration.
- To select and demonstrate the suitability of materials and techniques for embedding.

To meet its objective, experimental facilities will be designed and constructed in Serpong :

- Research and Development work on process formulation of immobilization with cement, using different types of hydraulic binder in different composition. Installation to support routine work facilities using well equiped embedding system for evaporator, spent - resin and compacted solid waste is under construction.
- Characterization of the embedded waste by studying the physical and chemical properties and distribution of radionuclides. The leaching rate behaviour will be studied by statical and dinamical methods either in laboratory scale or in full scale.

5. 2. Characterization of Natural Barrier.

The objectives of the component are ·

- To define physical and chemical characteristics of argillaceous materials - quarts, bentonite, vermiculate, apatite, etc. - in connection with transfer phenomena like exchange capacity, selectivity, sorption capacity and valency modifiers, to ensure containment of radioactivity for a long period of time.
- To develop mathematical models to study the interaction of radionuclides released from the waste, the natural barrier, and the ground water, for example :

thermal diffusion, corrosion, radiolysis, nuclide-transport, etc.

The data gained from this experiment will be used to develop and evaluate the designs, materials, method of construction of shallow ground repositories, and performance of the engineered barrier through physical models and simulation.

5. 3. Geotechnical Engineering and Geoservices.

In general, geological formations that posess a certain degree of plasticity and are free of circulating ground water would be most favourable for the site of shallow ground repositories.

To support the long term options, experimental drilling should be planned and be performed at several potential areas in Indonesia. The geotechnical investigation will be conducted in cooperation with other governmental institutions and other universities to study detailed surface geology, lithology, hydrology, and water table.

Laboratory study on behaviour of undisturbed log samples will be also done in connection with Simulation Test for Environmental Radionuclide Migration. The goal of this programme is to perform radionuclide migration tests under natural soil layer conditions.

Migration of radionuclides is one of the most important factors to be considered when carrying out safety analysis of a repository for radioactive waste in a wet geologic formation. This is particularly important in Indonesia where precipitation rate is high.

The knowledge gained will be used in developing methods to characterize potential disposal sites.
The objectives of the experiments are to study the correlation between surface and subsurface features, hydrological and geochemical system of the soil used as the natural barrier.

6. CONCLUSION.

A comprehensive programme of research and development on radioactive waste management has already well defined to meet the requirement for the future nuclear science and technology development in Indonesia as technical support of routine work for quality improvement to ensure that the processed low and medium wastes could be stored ultimately in shallow ground repositories safety and economically.

The interim spent fuel facility (ISFSF) will be constructed at Serpong to provide space for interim storage of irradiated fuel elements and high activated used components which is accumulated during 30 years of MPR-30 operation.

However, a period of many years will elapse before industrial full scale disposal operations are carried out to achieve nuclear power plant programme.
The need for continuation of R & D should be attributed to the need of improving the understanding of some specifics of radioactive waste management, and undoubtly, the viability of the disposal concept.

BATAN fully participates in international information exchange and waste management research projects. This ensures that Indonesia has access to technological advances on alternative disposal methods.

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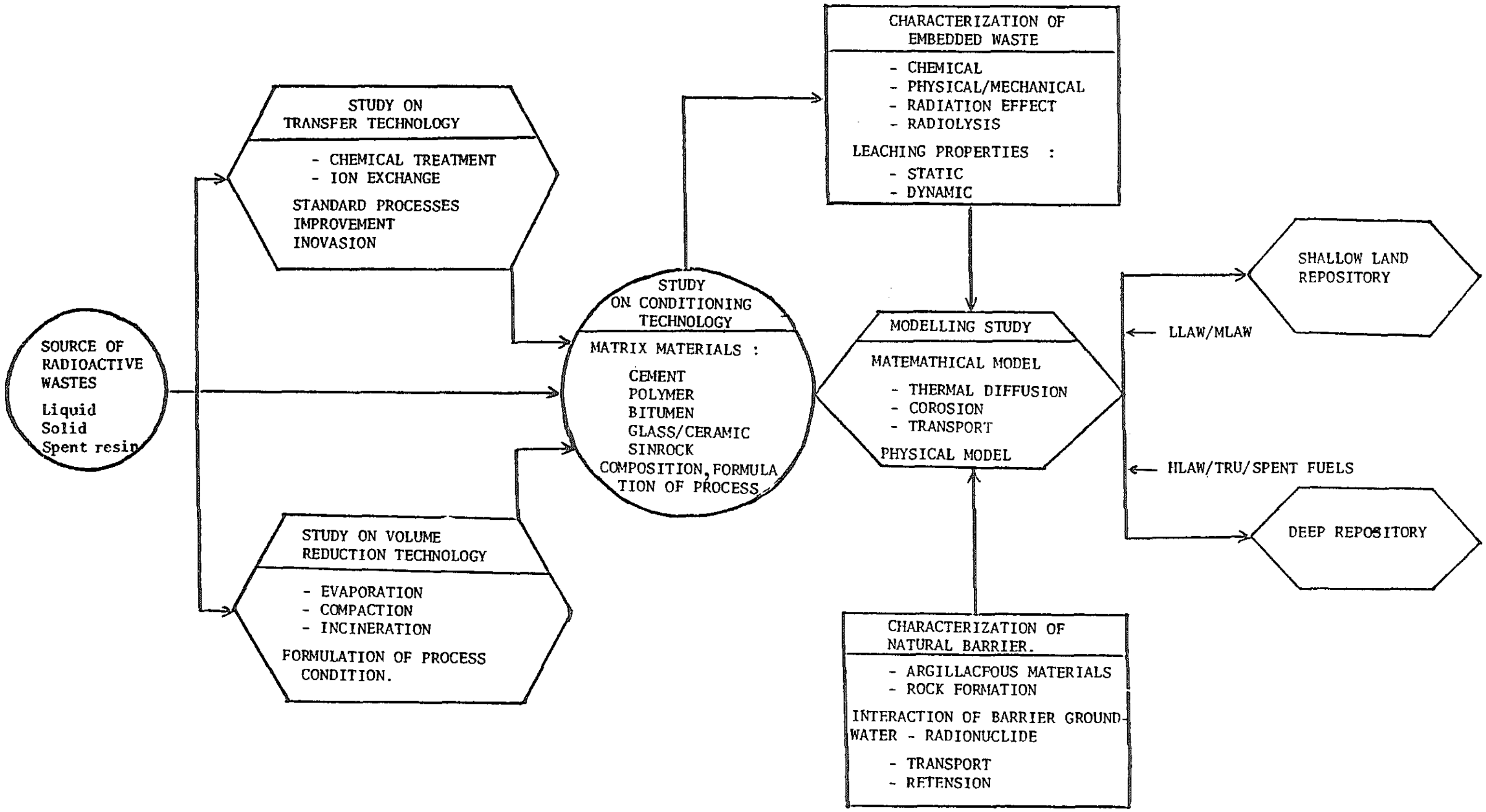
BATAN PROGRAMME ON R & D RAD.WASTE MANAGEMENT



FACTORS TO BE CONSIDERED IN ESTABLISHING A RADWASTE MANAGEMENT SYSTEM.

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Abstract

- Correlation between the overall nuclear program and the waste management concept.
- General objectives of the waste treatment facilities.
- Environmental conditions influencing the layout.
- Impact of waste disposal options.
- Factors influencing the capacity.
- Time aspects involved in the establishment of a waste management system.

In establishing a radwaste management system a number of factors have to be considered. Their influence on the general concept and on the layout of particular plants will be discussed below.

Correlation between the Overall Nuclear Program
and the Waste Management Concept

Radioactive waste management has to ensure that radioactive wastes arising from nuclear activities are safely and economically treated and disposed of. However, prior to constructing facilities for the management of waste, a national waste management policy and a basic technical concept have to be elaborated. They must be based on the long term general nuclear program and a political strategy.

The scope of the nuclear program is of primary importance to the layout of the waste management facilities and the waste management policy. Only small amounts of radioactive wastes with low activity levels arise from the application of radionuclides. As most of the radionuclides applied have short half-lives, collection of the waste and interim storage until the radionuclides have sufficiently decayed for being dis charged or disposed of as inactive waste may be the most appropriate method of waste management. The necessary installations are very simple and also the waste management policy can be very simple. The fabrication of nuclear fuels also leads to only small amounts of low level waste with, however, long-lived radionuclides.

Nuclear power plants produce rather large amounts of low and small amounts of medium level wastes and call for a more extensive system. They also necessitate a concept for the management of spent fuels (retrievable storage - disposal - reprocessing) including ideas about the time horizons. Besides low and medium level wastes also high level wastes arise from reprocessing of spent fuels and mixed oxide fuel fabrication. Most of these wastes contain at least small amounts of long-lived trans uranium elements. Reprocessing and mixed oxide fuel fabrication there fore require an important and comprehensive waste management system and waste management policy.

An adequate waste management policy has to define clear political boundary conditions. It is generally accepted that the radiation exposure resulting from waste management should be kept as low as reasonably achievable and that radiation exposure of future generations should not be higher than that of the generation that had the advantages from nuclear technology. There is still a number of other general rules. They are, however, not sufficient for practical purposes. A national waste management policy must go further into details. A good example is the release of radionuclides into the environment together with the effluents. Modern technologies make it possible to keep them much lower than necessary from the point of view of radiological protection. This raises the question if only those measures should be taken which are necessary for radioprotection or if should be done what is technically feasible. Generally speaking, the often encountered question "how safe is safe enough" calls for political guidelines. This implies that the waste management policy cannot be based only on technical and safety but also on socio-ethical and political considerations.

General Objectives of Waste Treatment

The primary objective of waste treatment is to

- separate the radionuclides from the bulk waste or
- concentrate the radioactive waste into smaller volumes;
- convert the residues into a waste form suitable for transport, interim storage and disposal;
- separate the radionuclides from the liquid and gaseous effluents to such an extent that they can be released into the environment safely and in conformity with the regulations.

Besides routine operations, waste treatment plants could also fulfill the task of serving as testing facilities. In this case, more flexibility would be necessary than for routine operation alone. Also training programs could be thought of. This would call at least for bigger locker rooms for the staff. If the plant is to be used for demonstrations to visitors, a special entrance and locker room and perhaps a visitor's gallery should be provided.

A decision must be taken whether the plant should be used only for the treatment of wastes arising at the site or if it should act also as a regional or central facility. Furthermore, it must be decided if it has to fulfil only the near-term needs or also future ones.

Practically all facilities necessary for the treatment and disposal of radioactive wastes are today available on the market. When deciding on their implementation it has also to be decided wether they should be purchased key-turn from competent companies or not. In the latter case, consultants and more time will be necessary.

Information on characteristics of the individual waste treatment processes, their advantages and their shortcomings are given in the paper "Principles of and Experiences in the Treatment of Low Level, Medium Level and TRU-Element Bearing Radioactive Wastes." The aspects outlined in that paper have to be considered together with those proposed in this paper for the selection of a waste management system.

Waste Amounts Arising in Nuclear Facilities

Prior to the design of waste treatment plants careful and comprehensive estimates have to be made of the volumes of future wastes arisings, their chemical and physical nature, activity level and type of radionuclides involved. This is not easy but a lot of experience is already available in this field from operating facilities.

The amounts and characteristics of radioactive waste arisings in a nuclear facility depend largely on the type of operations carried out. They depend also on the measures taken to keep the arisings small and on the experience and discipline of the staff. The average values of liquid effluents produced in laboratories are 0.1 to 5 m^3 per person and year. In nuclear reactors several thousand to a few ten thousand cubicmeters of liquid effluents my arise per year, depending on the type and size of the reactor and the waste collection and treatment system chosen. The production of liquid effluents in the fabrication of nuclear fuels amounts to a few m^3 per ton of fuel fabricated.

The production of solid waste amounts to 0.1 - 5 m^3 per year and person in laboratory work, a few hundred m^3/a in nuclear reactors and a few m^3 per ton of nuclear fuel fabricated.

Factors Influencing the Capacity of Waste Treatment Plants

The steadiness in arisings is an important factor in estimating the capacity of a liquid waste treatment plant. If waste does not arise at a steady rate, either a storage capacity for untreated wastes must be provided to buffer peak arisings or the capacity of the treatment facilities must be conceived for peak arisings. The most reasonable solution usually a compromise between these two extremes. A combination of spare tanks and spare treatment capacity will be the technically most reasonab le and the most economic solution. Also it has to be borne in mind that treatment plants need regular maintenance. During the maintenance period they are not available for operation. Furthermore, equipment may fail. The time needed for repair or replacement must also be taken into account in estimating the plants storage and treatment capacity.

For solid wastes no large spare treatment capacity is required as spare storage capacity will be cheaper and fulfils the task very well. Provisions have also to be made for the retirement of old facilities.

The capacity of interim storage facilities for conditioned waste will depend on the availability of a repository. As it is not very expensive, an ample capacity should be conceived. A storage capacity for several years seems a minimum in any case.

Environmental Conditions Influencing the Layout

Prior to the selection of treatment processes for radioactive effluents, the capacity of the environment for taking up the residual radionuclides has to be established. If, e.g., a plant can discharge its liquid effluents to a large river or to the sea, greater amounts of radionuclides will be tolerable then if the effluents are discharged into small water bodies. The utilization of the water, e.g. for irrigation or as drinking water, are other important factors, as are the national or local discharge policy. All these factors have an influence on the se lection of a treatment process because they achieve different degrees of radionuclide separation.

Impact of Waste Disposal Options

Quite often simple and cheap waste treatment processes achieve only a modest volume reduction, whereas processes leading to a high volume reduction are usually more expensive. The selection of waste treatment processes with a view to reducing the volume to a certain extent will therefore largely depend on the space available for waste disposal and on its costs.

The selection of waste forms will be influenced by the characteristics of the repository. If a repository is completely isolated from circulating ground water or if the time the water needs to reach the biosphere is long compared to the half-life of the radionuclides, the leach resistan ce of the waste forms will be of minor importance only and vice versa. Also some other waste form requirements, e.g. mechanical stability, gas release etc. may depend on the characteristics of the repository.

General Technical Aspects in Planning Waste Treatment Facilities

Waste treatment facilities must be subjected to the general rules applicable to the construction of nuclear installations. As usually non-sealed radioactive materials have to be handled, provisions have to be made against the spread of contamination. Walls and floors must be designed so as to be easily decontaminable. An adequate ventilation system has to be installed. In case of shielding requirements, which are not necessary for low level wastes, the floors of the buildings must be capable of carrying the corresponding heavy loads. Experience is available in all these fields.

Provisions have also to be made for the retirement of old facilities. ies. The possibility of easy extension should be foreseen for all plants.

In the waste treatment facilities rooms have to be provided for the health physics activities and for analytics and process control. In all plants space has to be provided for monitors. Also an adequate store for spare equipment may be necessary.

Time Aspects in the Establishment of a Waste Management System

In order to have available the waste treatment facilities in time, it must be borne in mind that the planning phase may require 1-2 years or even more. This includes the elaboration of a plant philosophy and estimations of the plant capacity. At a new site the discharge limits have to be fixed and all other rules have to be elaborated. Also the waste form requirements must be fixed, cost estimates made, etc. After the establishment of at least preliminary plans and cost estimates the budget can be set up and the money procured. The construction of the plants may require 2-3 years, depending on the complexity of the plant and the organization of its realization. Also some time will be needed for the training of the staff and for startup.

Setting up a repository will need much more time. As a first step, careful geographic, geologic, hydrologic and meteorologic studies have to be carried out. After site selection, the land has to be purchased. Often some infrastructure, (e.g. roads, railway connection, harbor) will have to be installed. Furthermore, a safety assessment has to be elaborated. It must be approved by the competent authorities. Also public ac ceptance has to be obtained. It might be wise to start the operation of the repository with an experimental phase limited to several years in order to demonstrate to the public that the repository can be operated safely. Unlimited disposal could start after that.

There is plenty of time for the establishment of a repository, provided that sufficient interim storage capacity is available and the long range time schedule has been announced and explained to the public from the beginning. The public will usually accept more easily a careful long range than a greatly speeded up concept.

Organization

Prior to starting operation of waste management facilities the responsibilities for plant operation, health physics, authorizations for discharges, maintenance, etc. have to be fixed. It is also necessary to work out a complete documentation of the entire facility, to elaborate fixed plans for maintenance, and to document and evaluate all results of operation.

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PRINCIPLES OF AND EXPERIENCE IN LOW LEVEL, MEDIUM LEVEL AND TRU ELEMENT BEARING RADIOACTIVE WASTE TREATMENT

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Abstract

- Treatment of Low and Medium Level Liquid Wastes
  . Chemical Treatment
  . Ion Exchange
  . Evaporation

- Conditioning of Low and Medium Level Liquid Waste Concentrates
  . Cementation
  . Bituminization
  . Incorporation in Plastics
  . Drying

- Treatment of Low and Medium Level Solid Wastes
  . Compaction
  . Incineration

- Off-gas and Exhaust Air Treatment
  . Noble Gases
  . Particulates
  . Iodine

- Treatment of TRU Wastes
  . Treatment together with Low and Medium Level Wastes
  . Recovery of Plutonium
  . Separation of TRU Elements from Materials and Wastes
  . Conditioning

- Transport and Interim Storage

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1. The Treatment of Low and Medium Level Liquid Wastes

Low level liquid effluents arise in all nuclear facilities and constitute the largest portion of all radioactive wastes. Although a uniform worldwide waste classification system does not exist, liquid wastes with an activity content of $< 3.7x10^7$Bq ($< 10^{-3}$Ci) beta-gamma per m^3 are often called low level. According to the same system, liquid wastes containing $3.7x10^7$-$3.7x10^{14}$Bq (10^{-3}-10^4Ci) beta-gamma per m^3 are classified medium level. Their volume is much smaller than that of the low level effluents. esides a few organic liquids, most liquid wastes are waste wat er or aqueous solutions.

The objective of the treatment of low and medium level aqueous wastes is to separate the radionuclides from the water to such an extent that it can be safely discharged into the environment or reused. The small fraction containing the separated radionuclides together with in active matter is transformed into a solid waste form suitable for in terim storage, transport and disposal. Organic liquids are either cleaned and reused, incinerated or transformed into a disposable waste form.

The most frequently applied methods for the treatment of aqueous effluents are precipitation, ion exchange and evaporation.

1.1 Chemical precipitation or flocculation are relatively simple and inexpensive processes. They are suitable mainly for the treatment of effluents with low activity and high salt and mud contents. Their effectivity depends largely on the chemical and radiochemical composition of the waste water. If it is known which radionuclides are present, specific reagents can be applied, e.g. phosphates for the precipitation of strontium, heavy metal (Cu, Ni...) ferrocyanides for cesium, etc. The effectivity of radionuclide separation can be increased by addition of the same or allied inactive ions (e.g. Ca for Sr). In such cases, decontamination factors ($DF = \frac{\text{activity before treatment}}{\text{activity after treatment}}$) up to 10^3 can be achieved.

If the radiochemical composition is not known, only non-specific flocculation processes can be applied, e.g. addition of Fe- or Al-salts and precipitation by rise of pH or precipitation by carbonates after addition of e.g. Ca. In such cases the DFs amount to only 2-100. The effectivity of chemical precipitation and flocculation is largely reduced by the presence of complexing compounds in the effluents. The precipitation/ flocculation can be carried out batchwise or continuously.

The precipitates are separated from the liquid by filtration or centrifugation. This is the only delicate step in the whole process.

1.2 <u>Ion exchange processes</u> are based on inorganic or organic ion exchange materials. Inorganic ion exchangers are usually ion selective and can therefore be used for the separation of specific radionuclides after chemical flocculation. The DFs amount up to 10^3. Inorganic ion exchangers are sometimes produced by coating a cheap basic material, e.g. silicagel, with the exchanger material. In this way, the amount of expensive exchanger material can be reduced and/or the hydraulic properties of the exchangers improved.

Organic ion exchange resins are high-molecular compounds, often on the basis of polystyrene. They contain active groups, e.g. $-SO_3H$ groups for binding cations or -OH for binding anions. Accordingly, they are called cation or anion exchangers. They are applied in the form of beads in columns with a perforated plate or in the form of powders as precoating material in centrifuges or filters. Organic ion exchangers are particularly suitable for the decontamination of low salt containing clean solutions. They are applied everywhere for cleaning the water from the primary circuits of reactors and of fuel storage ponds. They also can beused advantageously for the post-purification of evaporator distillates if this is necessary.

Ion exchangers separate only radionuclides present in the water as ions. Complexing agents jeopardize their efficiency. Effluents with a high salt content lead to frequent exhaustion of organic ion exchangers and therefore cannot be treated advantageously by this method. Mud and other solid matter must be separated previously from the effluent as their deposition on the surface of the ion exchangers would reduce their efficiency.

Organic ion exchange resins can be regenerated after exhaustion (saturation of the active groups). Mineral acids are used for the regeneration of cation exchangers, alkaline solutions for anion exchangers.

1.3 Evaporation is the most effective and most universal but also the most expensive method. With the exeption of tritium and the very small amounts of radionuclides bound in steam-volatile organic compounds, and the few radionuclides which can become volatile under certain circumstances (e.g. I, Ru, Te), all other radionculides are almost quantitat vely separated from the liquid effluents. To prevent the carryover of water droplets and, consequently, of radionuclides, the vapor is cleaned by baffle plates, packed colums, venturi scrubbers, fiber filters, etc. DFs of 10^4-10^6 can be achieved by appropiately designed evaporators. This is far more than required for most effluents. Whenever further decontamination should be required, this can be done by second evaporation or by ion exchange.

Chloride free solutions can be evaporated under acidic conditions whereas chloride containing effluents are usually alkalized in order to prevent corrosion. In alkaline solutions the tendency of foaming is increased. Foaming can be controlled by proper design of the evaporator and by addition of antifoaming agents.

Several types of evaporators have been used. Natural or forced circulation evaporators are very often installed. Especially the first are simple in design and need only little maintenance. The disadvantage of both types is their large consumption of energy which is a result of annihilation of the whole latent evaporation heat in the condenser by cooling water. If waste heat is available, the high energy consumption is not important. Wiped film evaporators are equal in energy consumption but can achieve a high salt concentration (up to 40 wt.% as compared to 15-25 wt.% in most other types).

More economically with respect to energy consumption are the vapor compression evaporators. In these units the vapor generated in the boiling solution is passed through a compressor and by compression is heated up to about 140C. This vapor can then be used for heating up its own evaporator. In this way the whole latent evaporation heat is recover ed and life steam is needed only for startup. The condensate is used to preheat the raw water. Therefore, neither cooling water is needed. As such vapor compression evaporators are somewhat complicated in their design and need frequent maintenance, their use is restricted to low level wastes. For these, they have been applied very successfully.

2. Conditioning of the Residues Arising from the Treatment of Low and Medium Level Liquid Wastes

From the liquid effluents treatment various kinds of residues arise. They contain all radionuclides and inactive substances separated from the effluents and are either concentrated aqueous solutions, sludges or ion exchangers with a large percentage of water. To make them suitable for disposal, they must be converted into a solid product. This should not be easily dispersible, i.e. it should form a quasi-monolytic block. They also should fix firmly the radionuclides thus preventing leaching by water and salt brines. Finally, waste conditioning should, if possib le, also achieve a volume reduction. Today the most frequently applied methods for low and medium level waste concentrate conditioning are cementation and bituminization. At a smaller degree incorporation into plastics or evaporation to dryness, followed by packaging into special containers, are applied.

2.1 Fixation in cement is simple and cheap in terms of equipment and operation, especially in case of in-drum mixing. Continuous mixers are slightly more complicated. Mobile cementing units are also available and can service several nuclear facilities. Cementation is done by mixing the waste concentrate with cement at the 1:1 volume ratio.

In contrast to the mechanical process of cementation, the chemical processes taking place during setting of the cement grout are very complex and can be disturbed by several waste components, e.g. boric acid, some organic acids or detergents. By pretreatment or the addition of special additives these problems can usually be mastered. Organic ion exchangers do not give very good waste forms. The leach resistance of cement products is not very high, especially if the leachant contains magnesium salts or sulfates. However, the quality of cemented residues is sufficient for most kinds of wastes and disposal options.

The main disadvantage of cementation is that it doubles the waste volume. The usual waste content of the final waste form is 10 wt.%. The waste volume is important if only limited space is available for disposal Due to the large volumes of wastes produced, the actually cheap cementation may lose this advantage, if storage, transport or disposal costs are high.

2.2 Bituminization

By mixing evaporator concentrates, precipitates or exhausted ion exchangers with hot bitumen the water evaporates and the residues are finely dispersed in the waste form. This becomes a solid block when cooled down. Mixer-extruders or wiped film evaporators are mostly applied in this process. Bitumen products usually contain 40 wt.% waste material. To avoid disturbances during the process the waste concentrates should not contain large amounts of thermally unstable substances. Nitrates do not disturb.

In comparison to cementation, the volume of the final waste form is 2 to 4 times smaller. Also the leach resistance of bituminized wastes is usually better. A fundamental disadvantage of bituminization is the inflammability of bitumen. However, wastes from nuclear power plants are rather flame resistant and a possible fire would not be self-sustaining. Practice has shown that also wastes with a high nitrate content can be safely bituminized. If packed in shielding containers, the products do not burn at all in standard fires as defined in the IAEA transport regulations.

Bituminization involves high investment costs but they pay off if storage, transport and disposal costs are high considering the small volume of the final waste form.

2.3 Organic polymers are used only to a small extent for conditioning residues from liquid waste treatment. Embedding of ion exchange bead resins is the method most frequently applied. By simply pouring styrene, divinylbenzene and a catalyst over the dewatered resins in a drum at room temperature a monolytic block is produced. Embedding in polyesters or epoxides is a similar process. Fixation of powdered ion exchange resins is more complicated. Embedding evaporator concentrates and sludges calls for drying before mixing, unless vinyl esters are applied.

Instead of thermosetting plastics also thermoplastics such as polyethylene can be used. They are heated beyond their melting point and then mixed with the waste as in bituminization.

The incorporation of ion exchange resins into thermosetting plastics is promising because it is a simple process. For this reason, the relatively high material costs are acceptable. Also mobile units are availab le for this process. The immobilization of sludges and evaporator concentrates in thermosetting resins and in polyethylene seems to be hardly competitive with alternative methods.

2.4 The transformation of water containing concentrates into a solid waste form without any binder has been investigated in the Federal Republic of Germany in recent years. Evaporator-dryers and in-drum-dryers are in operation in some NPPs. A relatively big volume reduction is achieved in this way. The potential dispersibility and low leach resistance of the solid residue -as not fixed in a binder- is compensated by high quality cast iron containers.

3. Treatment of Solid Wastes

The main objectives of solid waste treatment are reduction in volume and transformation of the residue into a waste form which meets transport and disposal criteria.

3.1 Compaction

Baling presses are relatively simple, inexpensive and robust apparatuses. However, they do not produce a high volume reduction. They are used mainly for low level wastes. The high investment costs and the complicated operation of schielded presses are usually not justified for medium level wastes which constitute only a small part of the solid wastes. If an incinerator is available, only non-burnable wastes are baled but in many places baling presses are the only devices for volume reduction of solid wastes. They can be found in almost all nuclear facilities.

In former times many baling presses generated a pressure of about 20 tons. With these presses a volume reduction of about 2 had usually been achieved. In order to reduce the volume even more, baling presses of up to 1500 tons capacity are installed today in some places. These so-called "supercompactors" attain an average volume reduction by a factor of 5. Practice has shown that it is advantageous to package the wastes into simple and cheap barrels and to bale them together with these barrels. The resulting pellets can then be packaged into standard drums. The free space is usually filled with concrete grout.

3.2 Incineration

The most appropriate method of treating burnable wastes is incineration. It allows a volume reduction of 1:20-1:80 to be achieved. The ash is usually fixed in cement. Several types of incinerators have been in operation for many years. Some of them have already reached a high degree of technical maturity.

At KfK a ceramic-lined shaft-type incinerator has been in operation for about 15 years. More than 15.000 m^3 of burnable waste have been treated so far. The flue gases pass an afterburner and are then cleaned by ceramic candle filters. If necessary, they pass then a wet scrubber. Final cleaning is always done through HEPA filters. The purified flue gases can be safely discharged to the atmosphere.

The extent of application of incineration varies widely from one country to another. The main reason are the relatively high investment costs against often low throughputs. The disposal situation is therefore the most important factor in decision making. Central incineration facilities may improve the economic situation.

4. Exhaust Air Treatment

The main contribution to the already very low dose commitment in the environment of nuclear facilities is made by the airborne radionuclides. They also constitute the main potential hazard for radionuclide release in case of accidents. Exhaust air and off-gas treatment is there fore an important part of the waste management system.

Airborne fine solid or liquid particles are separated very effectively from exhaust air in all nuclear installations by high efficiency particulate air (HEPA) filters provided that they are properly installed and not damaged during transport or installation. The correct function of the filter units can be checked by in situ-tests.

In all nuclear power plants the noble gases are released after an appropriate delay, very often by adsorption processes. Radioiodine is separated with high efficiency, e.g. by impregnated carbons. Special components are available to control high temperatures, shock waves, and high differential pressures. To avoid damage to the filters by excessive humidity or droplets, the air cleaning systems of modern plants are equipped with demisters followed by air heaters.

In the off-gases from chemical plants (reprocessing, waste treatment, etc.) also semi-volatile radionuclides like ruthenium or cesium may have to be separated. Furthermore, these off-gases may contain large amounts of water vapor and corrosive components, e.g. nitrous oxides. Therefore, the corresponding off-gas treatment facilities are often equipped with condensers, NO_x-adsorbers, wet scrubbers of different types, and demisters. Silver impregnated inorganic sorbents achieve very high iodine removal efficiencies.

5. The Treatment of TRU Wastes

Transuranium element (TRU) bearing wastes arise in significant amounts only from reprocessing spent nuclear fuels and from mixed oxide (UO_2/PuO_2) fuel fabrication. Even in these areas the waste volumes arising are relatively small as compared to those produced in nuclear engineering as a whole.

The TRU wastes are characterized by the long half-lives and high radiotoxicity of most TRU elements. Working with high levels of TRU elements calls for special precautious to avoid the spread of contamination (alpha-boxes, etc.). Besides, TRU wastes resemble low and medium level wastes, as far as their appearence and their content of beta/ gammaemitters is concerned, and high level wastes in terms of their long-term radiotoxicity. At present a comprehensive TRU waste policy is still missing in most countries. There is, however, a general agreement that TRU-wastes shall not be disposed of by shallow land burial.

In some countries TRU wastes are stored retrievably until regulations will be set up and/or a repository in a deep geologic formation will be available. In some countries TRU wastes are treated together with low and medium level wastes or according to the methods established for these wastes. With respect to TRU waste disposal it is important to bear in mind that TRU-elements -exept for neptunium- migrate in soils at a very slow rate only.

As long as only small amounts of TRU wastes arise, a treatment together with low and medium level wastes seems to be a reasonable approach provided that they are diposed of in a deep geologic formation. The main disadvantage lies in the fact that very small contents of TRU elements (in the ppm range) determine the long-term radiotoxicity of relatively large amounts of waste. Advanced TRU waste management concepts aim at recovering plutonium and concentrating the other TRU elements as much as reasonably achievable. The small volume residue is then converted into a very stable waste form. It seems possible to concentrate about 99% of the TRU element losses outside the high level wastes in about 1% of all final waste forms.

For this aim some special processes have been developed and are applied in some cases. The process applied for the recovery of plutonium from solid wastes depends on the chemical form of the Pu. Solid organic box wastes contaminated with PuO_2 are washed with water and detergents (recovery rate 60-95%). To free metals and other solid materials from PuO_2, a treatment with freon in an ultrasonic bath has proven successful. Equipment contaminated with $Pu(NO_3)_2$ is cleaned with diluted nitric acid. Equipment, contaminated with other TRU elements, can be cleaned by various decontamination techniques like vibratory finishing, electropol ishing, etc. Plutonium can be largely recovered from burnable wastes by acid digestion. In this process, the organic matter is decomposed by a hot mixture of nitric and sulfuric acid and the plutonium compounds are transformed into $Pu\,(SO_4)_2$ which can be recovered easily. Plutonium can also be recovered from the ashes of dry incinerators, but this is more difficult and the yield is lower. TRU elements can be removed from liquid effluents by chemical precipitation or inorganic ion exchangers.

After concentration into a small volume the TRU elements should preferably be immobilized in a high radiation, heat and leach resistant waste form. Lanthanide phosphates, the SYNROC components zirconolite and perovskite, and a mullite-corrundum ceramic have been proposed for this purpose. It has also been proposed to separate the TRU elements from high level waste by extraction and to fission them in a fast flux reactor. This, however, does not seem to be a realistic approach.

6. Transport and Interim Storage

The transport of low level solid wastes does not pose any particular problems and can be done by e.g. trucks or fork-lifts. The wastes must, of course, be properly packed and no outside contamination is permissible. Wastes with a dose rate 200 mrad/h at the surface and 10 mrad/h at 1 m distance have to be shielded. Concrete and steel containers are normally used for this purpose. Liquid wastes are transported in bottles if the volume is small or in tank trucks. Between individual buildings of a site liquid effluents can also be transferred in doublewalled pipelines.

For the interim storage of low level solid wastes simple store houses with a decontaminable floor are suitable. The storage of medium level wastes calls for a structure with shielded walls and remote handling devices. Alternatively, the wastes can be packaged into shielding containers and then stored in simple storehouses. In case of small amounts of medium level wastes, the latter approach will be cheaper. Liquid wastes should not be stored for an extended period of time. For interim storage corrosion resistant tanks, made of stainless steel, coated normal steel or plastic, and mounted in a water-tight trough are used. They are equipped with level detectors, a sampling system, and a circulating pump.

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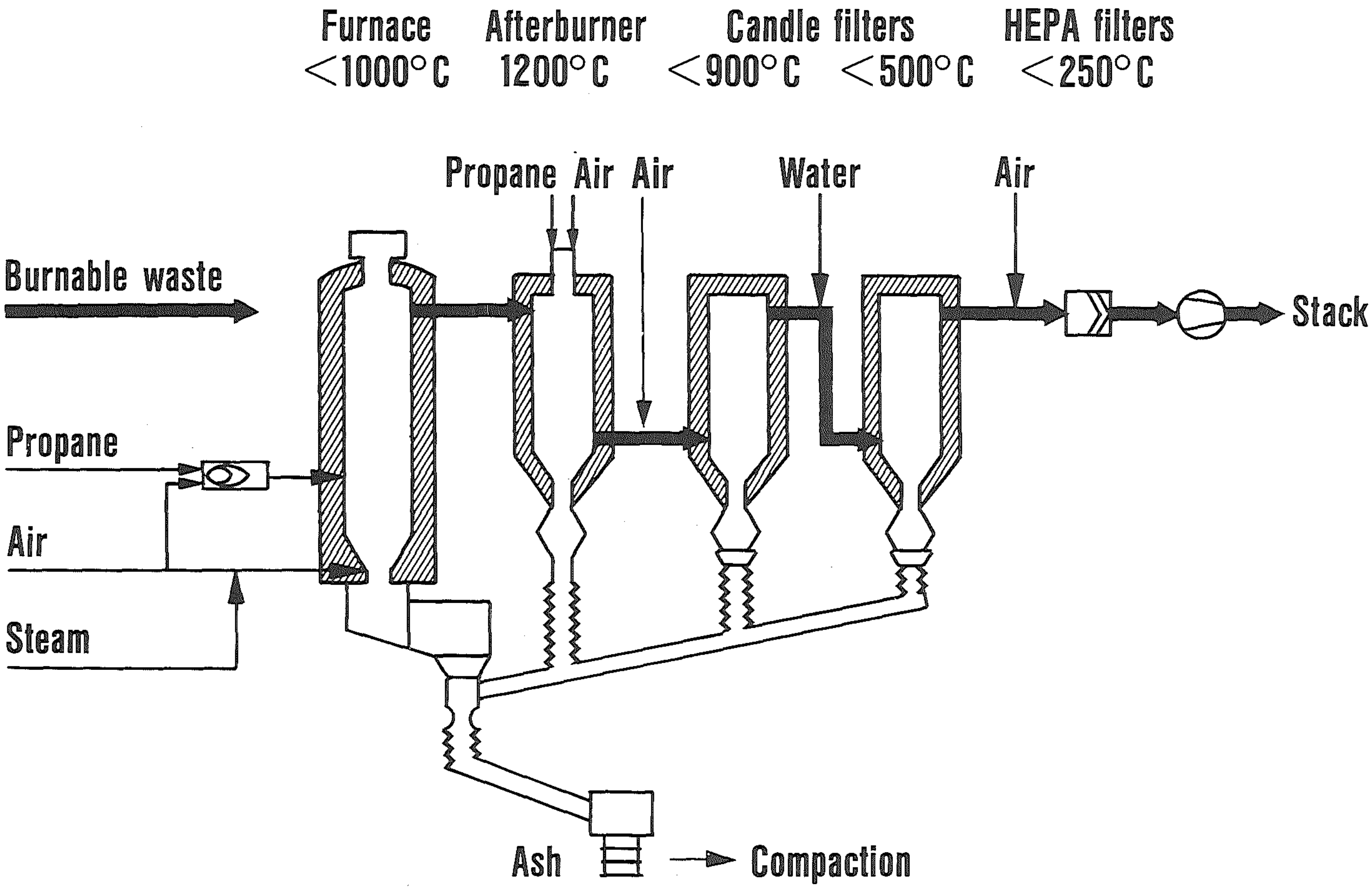

KfK Incinerator for Solid Radioactive Waste

CHARACTERIZATION OF LOW AND INTERMEDIATE LEVEL WASTE FORMS - QUALIFICATION FOR INTERIM STORAGE, TRANSPORT, AND DISPOSAL

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ABSTRACT

The objective of the waste conditioning process is to transfer the raw wastes into a waste form which fullfills the requirements for a safe handling, transportation, intermediate storage and disposal. The determination of the relevant waste form properties is performed by the waste form characterization.

For the low and intermediate level waste concentrates and solid wastes arising from the planned 350 MTHM/year reprocessing plant cementation is foreseen as the method for solidification.

The main objective of the characterization work performed at the Kernforschungszentrum Karlsruhe was to establish source term formulations for the cemented waste forms as input for safety analysis.

For the operation phase of a repository radionuclide mobilization from the waste packages via the gas phase, caused by mechanical or thermal impact has to be considered. For this reason, besides laboratory tests, experiments with inactive full scale samples were performed (200 l and 400 l drums) to determine quantitatively the activity release from the waste packages under defined thermal and mechanical stresses.

In order to evaluate source terms for the mobilization of relevant radionuclides via the liquid phase (post operation phase of the repository) as a function of time due to leaching and corrosion, detailed experimental work with simulated inactive and dopted (Cs-137, Sr-90, Pu, Am) laboratory samples and with inactive full scale samples was performed. The experimental work was accompanied by theoretical investigations to establish an improved basis for long term predictions.

INTRODUCTION

In the Federal Republic of Germany the waste management concept is based on disposal of all radioactive wastes in repositories in deep geological formations. In the repository the wastes are isolated from the biosphere by a system of multiple engineered and natural barriers. Liquid and solid wastes have to be treated and packaged to waste forms with known physical and chemical properties, which correspond to legal demands, especially the German Strahlenschutzverordnung.

The investigation of essential waste form properties has been performed within the waste form characterization for every waste type. On basis of these data and safety analysis the Physikalisch-Technische Bundesanstalt (PTB) proposes specification for waste products. The waste form characterization therefore provides an important contribution to judge the disposal capability.

To obtain comparable and acceptable results for essential waste form characteristics, e.g. thermic and mechanic properties, leaching- and corrosion resistance, radiolytic stabilty, capable investigation methods have to be fixed and standardized. In the FRG this work has been done since 1979 by the working group LLW/ILW waste forms.

Waste Types

To establish the investigation methods for the waste form characterization and for quality assurance the knowledge of physical and chemical properties of the raw waste and the matrix material is essential. Table I contents the raw wastes and the matrix material.

Table I

Matrix Materials used in the FRG for the fixation of LLW and ILW from reprocessing- and from power plants

raw waste	matrix material
aqueous LL and IL concentrates from reprocessing	cement (bitumen)
solid LL and IL Wastes from reprocessing	cement, concrete
IL-ION exchanger from reprocessing	cement
organic waste concentrate from reprocessing (n-TBP/dodecan mixture with 10 Vol.% dodecan)	polyvinylchloride (PVC)
LL-waste concentrates from power plants	cement, (bitumen, polyethylen)
IL ion exchanger from power plants	cement, polystyrene-poly-divinylstyrene (bitumen)
solid LL and IL wastes from power plants	cement, concrete

WASTE FORM PROPERTIES

Important waste form properties, which have been investigated in connection with the waste disposal are besides radionuclide inventories activity releases under thermal and mechanical stresses (operational phase) and activity releases from waste packages via the water path (post operational phase). Results of this investigations are presented in this paper.

Source term for the operation phase of the repository

Mechanical Impact

Mechanical impacts on waste packages during the operational phase of the underground repository in principle may cause release of small, contaminated particles (fines) which may be dispersed by the ventilation and thus create an airborne hazard.

For this reason, full scale experiments were performed to determine quantitatively the amount and the particle size distribution of the dust released from packaged inactive simulated cemented waste forms by mechanical impact. A point of special importance was the determination of the release of fines with a particle size 10 µm because the particles could be inhaled and thus create internal radiation exposure. In addition, laboratory experiments were performed for comparison of the fracture behaviour of different waste forms. The composition of the waste forms for the laboratory experiments is given in TABLE II.

TABLE II

Composition of Different Cemented Waste Forms

Waste Types	Binder	Waste Loading	w/c-ratio
evaporator concentrate ($NaNO_3$)	BFS-cement OPC	10 wght %	0.35 - 0.45
decontaminations * effluents	BFS-cement	2 wght %	0.50
Scrub water (NaCl) *	BFS-cement	4 wght %	0.40
Filter aid sludge	BFS-cement	7 wght %	0.50
bead resins	BFS-cement	10 wght %	0.28 - 0.33**
incinerator ash	BFS-cement	40-61 wght %	0.40 - 0.50
pyrolysis ashed	OPC	39 wght %	1.80
pyrolysis ashes	BFS-Cement	39 wght %	1.80
compacted trash ***	OPC-mortar	50-82 wght %	0.30 - 0.40

* used for cementation of incinerator ash
** free water
*** pellets Ø 500 mm, overpoured with mortar

Laboratory experiments

The results of laboratory experiments are useful to characterize waste forms and to compare different waste types, but they overestimate airborne release because they neglect the influence of packaging. Some similar laboratory tests have been performed within our investigations too, the results are reported here.

The impact resistance of small laboratory samples was investigated similar to Wallace and Kelly /1/. In the test prismatic samples 2x2x4 cm were impacted and crushed by a falling 1 kg-weight from 1 m height (10 impacts). The impact energy was 2,6 J/g. Particle size distributions were analyzed by sieve analysis according to DIN 4188 and Laserdiffraction techniques for particle sizes smaller than 50 µm.

Weight fractions of fine particles $\leq$ 200 µm for different waste types, surface area increase rates and ratios of surface area increase/impact energy are summarized in TABLE III. Cement products with compressive strengths $\geq$ 20 N/mm² yield weight fractions up to 5.8 weight % for particles $\leq$ 200 µm and up to 0.91 weight % for particles $\leq$ 50 µm. The average surface area increase yields a factor of 40 compared to the non crushed product, the average ratio of surface area increase/impact energy 20 cm²/J.

Full scale experiments (drop tests)

Description of the experimental setup

For the drop tests inactive simulated cemented waste forms (OPC 35, w/c = 0.35, 10 weight % $NaNO_3$) packed in 200 l steel drums were used.

The mechanical impact was applied by dropping the waste package from a defined height on to a reinforced concrete target (2x2x3 m, 20 tons) covered by a 80 mm thick steel plate. Different mechanical impacts could be realized using a crane with a maximum lift height of 65 m. Based on the package weight of about 500 kg and the applied drop height of 60 m the mechanical impact yields 3.10^5 Nm. This impact corresponds to the maximum mechanical impact considered for the safety assessments for the repository /2/.

To establish a closed system for the collection of the released dust, (under undisturbed conditions) the concrete basement was surrounded by a mechanically stable cage with mobile ceiling. For collecting a part of the airborne fines, a total of 30 filter units with microfilters (nucleopore 0.2 µm) were placed on the inner sides of the cage. The experimental equipment is shown in Fig. 1. From the amount of dust on the filters and taking into account the suck-off parameters, the dust concentration in the cage air volume and in consequence the source term can be calculated.

For the determination of the dust amount on the filter SEM-photographs of selected filter sections were performed and evaluated using an automatic picture evaluation system. In addition, the time dependence of the average dust concentration in the cage was measured by using a tyndallometer equipment. To obtain further information on package behaviour and dust spreading the impact on the waste package was observed by an installed video camera. In two experiments, the fraction with an aerodynamic diameter between 1 µm and 20 µm was determined using a cascade impactor.

TABLE III

Particle size distribution of fines after mechanical impact on cemented laboratory samples (impact energy 2.6 Joule/g)

	Weight Fractions				Surface Area	Surface Area
Waste Types	≤ 11 µm	≤ 50 µm	≤ 80 µm	≤ 200 µm	Increase (-)	Impact Energy (cm²/J)
evapor. conc.	2.3 E-3	9.0 E-3	-	3.4 E-2	44	21
decontamination effluents *	1.5 E-3	6.6 E-3	1.9 E-2	4.6 E-2	42	18
filter aid sludge	1.2 E-3	7.1 E-3	1.2 E-2	2.7 E-2	37	20
bead resins	2.1 E-3	9.1 E-3	2.4 E-2	5.8 E-2	47	28
incinerator ash	1.4 E-3	3.4 E-3	1.2 E-2	3.0 E-2	40	16
pyrolysis ashes						
OPC **		4.8 E-3	3.6 E-2	1.4 E-1	58	43
BFS-cement ***		2.8 E-3	1.9 E-2	5.7 E-2	44	30

* with 61 weight % incinerator ash
** compressive strength 4 N/mm²
*** compressive strength 20 N/mm²

Surface area of broken waste product:

$$A = \frac{6M}{S} \sum_{i=1}^{n} \frac{f_i}{\bar{x}_i}$$

A = Surface area of the product (m²)

M = total mass of the particles (kg)

S = density of the waste product (kg/m³)

fi = weight fraction of class i

$\bar{x}$i = average diameter of particles in class i (m)

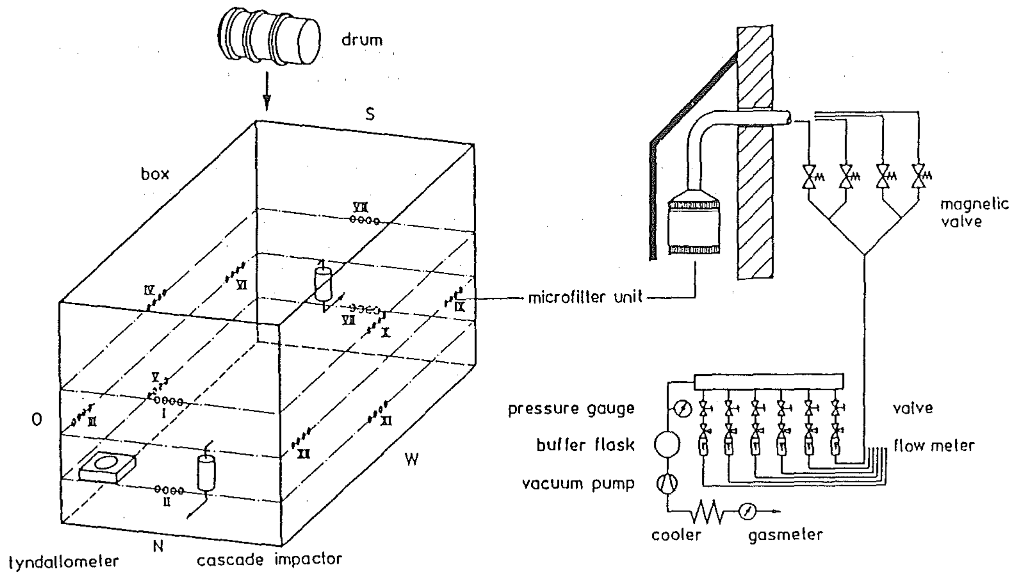


Fig. 1. Scheme of the experimental set up for the collection of airborne fines from the waste package after mechanical impact.

The result from 4 simular experiments show that the release of fines with a particle size $< 10 \mu m$ amounts to ≤ 1 g. This value corresponds to 10^{-4} % of the total inventory.

The released fraction with an aerodynamic diameter between $1 \mu m$ and $20 \mu m$ (impactor measurements) amounts to 1.5 g.
This values and the dust concentration measured with the tyndallometer equipment show a good agreement within the range of the same order of magnitude. From these results it is concluded that for homogeneous cement waste forms the activity release amounts also to 10^{-4} % of the radionuclide inventory.

To obtain also information about the waste form destruction at the end of the experiment all the crushed waste form material released from the package was collected for further analyses. The total material weight was determined and a sieve analysis was performed. By the applied separation technique (sieve analysis) only the total fraction with a particle size > 0.063 mm could be determined. For a more detailed analysis of the particle size distribution in this range other separation techniques have to be used. The total fraction with a particle size ≤ 0.125 mm amounts to 518-608 g, the fraction 0.063 mm amounts to 86-202 g.

Thermal impact tests

The effects of thermal impacts are especially important for organic waste forms, e.g. bitumen waste forms, because the matrix material is inflammable. Detailed investigations with bitumen/$NaNO_3$ waste forms were performed in the past /3/.

To complete the knowledge about the behaviour of cemented waste forms in case of thermal impact, the here described experiments were performed.

Cement as an inorganic binding material is not inflammable, but cementitious waste forms contain a certain amount of water, which can be removed by heating, and in addition organic materials, e.g. ion exchange materials or burnable trash, which can be decomposed by pyrolysis. The release of water or pyrolysis products from cemented waste forms can cause activity release, e.g. by formation of radioactive aerosols.

Hydrated cement contains in principle two different forms of water. The free or unbound water is easily removed from the cement by heating to a temperature of 105°C.

The other form is bound in the various hydrated phases and as interlayer water. Release of this water depends on the decomposition points of the hydrated phases and therefore strongly on the temperature. For this reason water release from a cemented waste form in case of an accidental fire situation clearly depends on the energy input.

Experimental

To determine the activity release from cemented waste forms containing $NaNO_3$, laboratory experiments with inactive simulated as well as experiments with inactive simulated full scale samples were performed.

Thermographimetric-Analysis and DifferentialThermo-Analysis Investigations were performed with inactive simulated laboratory samples. Most of the obtained results are already described in the literature /5, 6/ but for a complete set of data it seems advantageous to perform these experiments.

Samples of different compositions were investigated, that is cement without $NaNO_3$ and cement containing 10 weight % $NaNO_3$. Fig. 2 shows the calculated weight losses from the Thermographic-Curve for the two different sample compositions. The results indicate very clearly that most of the weight loss occurs in the temperature range up to 150°C - 200°C. Free pore water is liberated up to a temperature of 105°C and amounts to one third of the total weight loss for this sample composition. An interesting point is the observed weight loss for the $NaNO_3$-containing sample in the temperature range between 500°C and 700°C. This increase of weight loss is probably due to decomposition of nitrates and this is also indicated by the total weight loss of 31% because the water content of these samples is only 25.7 %.

Field Tests with 200 l and 400 l Packages

In the field tests 200 l- and 400 l-steel drums containing simulated cemented waste forms (evaporator concentrate, filter aid sludges, incinerator ashscrubwater, organic bead resins, high force compacted trash) were exposed to an oil fire or isopropanol fire of 30-110 min duration (flame temperature 800-1000°C).During these experiments the temperature distributions inside the drums, weight losses and element losses (Cs, Sr, Eu, I) were measured.

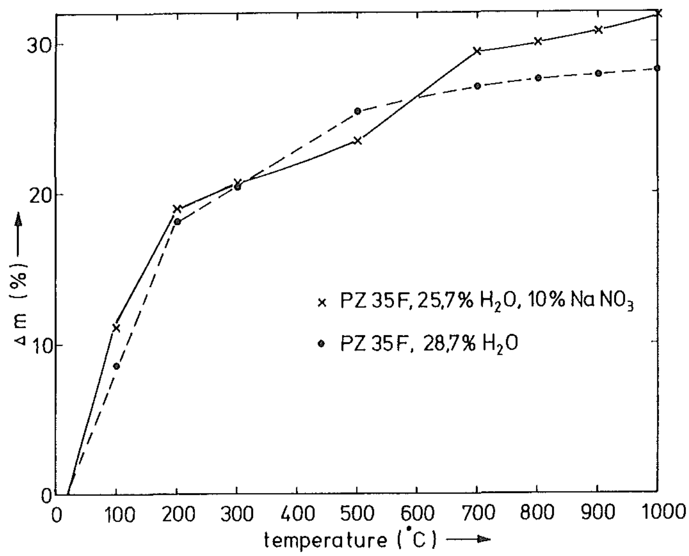


Fig. 2. Weight loss of cemented waste forms (laboratory scale) as function of temperature.

Some results of detailed temperature profile measurements in a homogeneous waste form (evaporator concentrate) are shown in Fig. 3. The maximum temperature at the package surface is 500-660°C. In the waste form a strong temperature gradient exists:

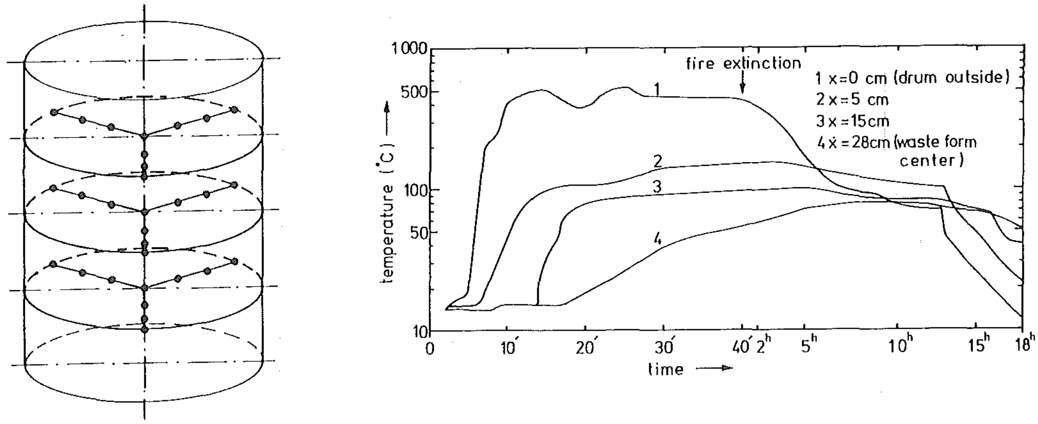
- max. 10 mm from the outer surface temperatures 350°C.

- max. 50 mm from the outer surface temperatures 100°C.

- max. temperature inside the waste form 80°C 10 hours after the end of the fire.

This result indicates very clearly that water and pyrolysis residues are released only from the outer parts of the waste form. In case of heterogeneous waste forms, e.g. compacted burnable trash in pellets, overpoured with mortar (10 mm mortar thickness) higher temperatures inside the pellets up to 400°C can occur, due to the different heat capacity of the heterogeneous structure and pyrolysis reaction inside the waste.

Weight losses of 200 l drums are 10 - 16 kg after 30 min. fire and 16 -23 kg after the 60 min. fire test. This corresponds to 2.3 - 4.0 weight % and 4.0- 7.3 weight % respectively. The highest weight losses had been obtained with compacted burnable trash (23 kg/7.3 weight %). Fire tests with 400 l-samples (evaporator concentrates) yielded weight losses of 14-15 kg (1.8-2.0 weight %) after a 30 min. fire test.



(a) (b)

Fig. 3 Positions of the thermocouples in the cemented waste form (a) and time dependence of the temperature distribution (b) in the waste form (upper level of thermocouples) during the first test (field test, 40 min. oil fire).

The element losses were investigated by two different off-gas sampling methods:

- total condensation
- total exhaustion and aerosol filtration (Fig. 4).

Cs, Sr, Eu and I-releases from different cementitious waste forms after a 60 min. fire test (200 l drums) are summarized in TABLE III. Homogeneous cement products yield following results:

Total released fractions

Cs $\leq$ 3 E-4
Sr $\leq$ 9 E-5
I $\leq$ 2 E-4
Eu $\leq$ 9 E-6.

High force compacted burnable trash shows higher release rates, due to higher product temperatures inside the waste:

Total released fractions

Cs $\leq$ 2 E-3
Sr $\leq$ 1 E-4

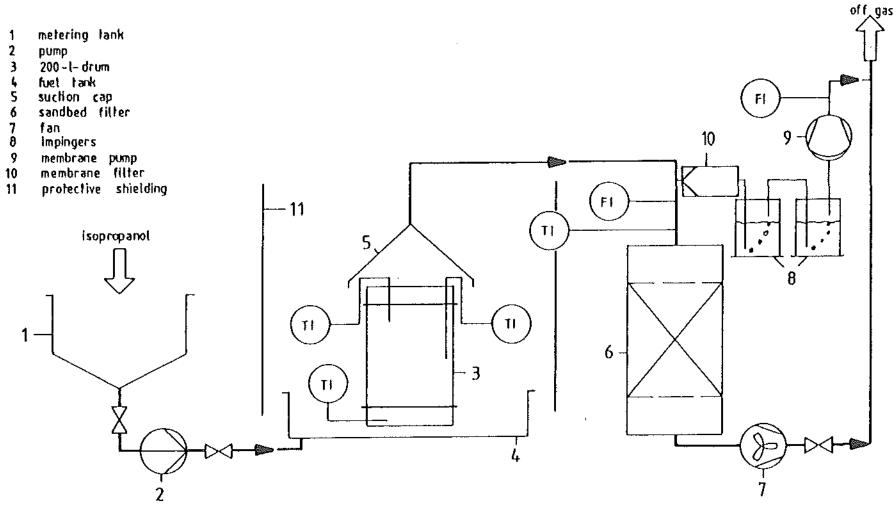


Fig. 4 Flow sheet of experimental set up for the fire field test.

TABLE IV

Element-specific release fractions from different waste forms after 60 min. fire test, 200 l-drums *

Cemented Waste Form	Release Fractions (-) Cs	Sr	Eu	I
Evaporator conc.	8 E-5	2 E-5	4 E-6	-
Bead resins	8 E-5	-	5 E-6	2 E-4
Incinerator ash/ scrub water	3 E-4	9 E-5	9 E-6	-
Compacted Trash	2 E-3	1 E-4	-	-

* without lid

The data apply to cement products solidified without supernatant water in open steel drums without additional shielding.

Volume changes and water losses during heating cause some crack formation at the surface of homogeneous cement products. An outer layer of 5 mm product shows colour changes, indicating high temperatures and pyrolysis effects. During heating of overpoured compacted burnable trash a volume increase of pellets occured (2-3 Vol.%) which caused partial destruction of the mortar layer surrounding the waste. Inside the pellets an outer layer of 5-10 mm was thermally decomposed.

In summary the results of the experiments give a clear indication that any activity release from cemented waste forms under thermal impact is very low. For example, the activity release from $NaNO_3$-containing cemented waste forms is 3 orders of magnitude lower than the activity release from $NaNO_3$-containing bituminized waste forms /3/.

SOURCE TERM FOR THE WATER PATH WAY

The source term for the water path in this paper is described for IL/LL-evaporator concentrate cement waste forms. Similar results for other waste types are available.

A representative composition of ILW concentrates from a reprocessing plant with Purex flowsheet for LWR fuel is given in TABLE V.

TABLE V: ILW-concentrate from a Purex reprocessing plant
(LWR fuel, burn-up 30 GWd/mt H.M.,
U 235 3.5%, cooling time 5 a).

specific Beta-Activity $\leq 10^{13}$ Bq/m³
specific Alpha-Activity $\leq 10^{10}$ Bq/m³

main activity carriers:
Cs 137/Ba 137m; Ru 106/Rh 106; Ce 144/Pr 144;
Sr 90/Y 90; Sb 125/Te 125; Cs 134

solid content: 25-35 wt% ($\geq$ 90% $NaNO_3$). /6/

Typical cemented evaporator concentrate waste form properties are listed in TABLE VI.

TABLE VI: Typical waste form properties
(cemented evaporator concentrate waste form)

Matrix: Ordinary portland cementstone (OPC)
Main components of concentrate: $NaNO_3$
solid load in the waste form : 5 - 15 wt.%
Water content: 20 - 30 wt.%
Density : 2 g/cm³
Porosity : 25 Vol.%
Air porosity : 2 - 4 Vol.%

Compressive strenght : 15 N mm^{-2}
Considerable water release: T $\geq$ 105°C (p = 1 bar)
Heat conductivity : 0.5 $W \cdot m^{-1} \cdot K^{-1}$

Radiation resistance $\leq 10^{10}$ rad

Radiolysis gas formation: H_2 : 0.3-0.8 ml/kg·10^6 rad
O_2 : 0.1-0.2 ml/kg·10^6 rad /7/

For the aqueous pathway radionuclide releases from cemented waste forms have been investigated in detail in water and salt brines. The leachability of, e.g., Cs 137-tracer amounts in saturated NaCl brine from a simulated ILW concentrate cement waste form in laboratory scale using the IAEA leach test is shown in Fig. 5.

The volume of the leachant is ~ 10 times the sample volume. From such curves a diffusion constant and the leach rates can be calculated. Typical values for the integral leach rates are (1 year, 25°C):

$10^{-3} - 10^{-4}$ cm/d for Cs, Sr

$10^{-6} - 10^{-7}$ cm/d for Co, Sb, I

$10^{-6} - 10^{-7}$ cm/d for TRU-elements

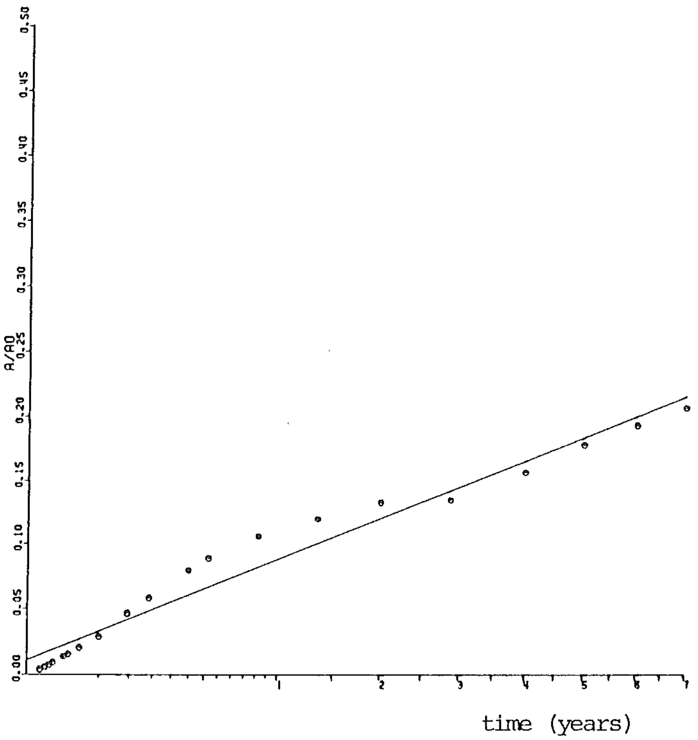


Fig. 5 Cs release from laboratory scale ILW-OPC waste forms in sat. NaCl-solution (OPC, W/C = 0.4, 10 weight% $NaNO_3$)

In a brine rich in $MgCl_2$ (Q-brine) - which has to be considered for safety analysis as possibly attacking the waste form - the release of Cs cannot be described by a simple diffusion process, as can be seen in Fig. 6 .

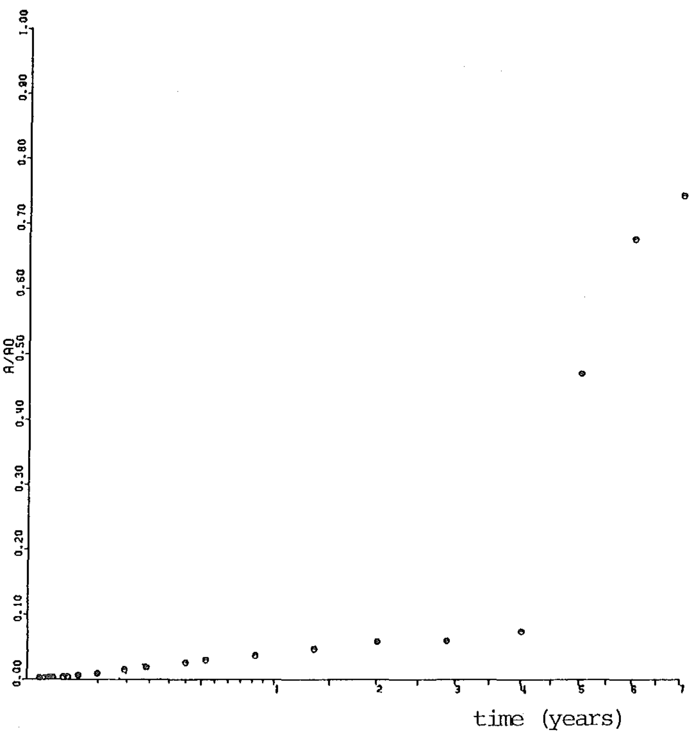


Fig. 6 Cs release from laboratory scale ILW-OPC waste forms in Q-brine (OPC, W/C = 0.48, 10 weight% $NaNO_3$)

The kinetics in this case are determined by three corrosion processes:

- leaching of soluble compounds
- exchange reactions ($Ca(OH)_2 + MgCl_2 \rightarrow CaCl_2 + Mg(OH)_2$)
- formation of new phases causing swelling.

Leach experiments, x-ray analysis of phase composition and determination of element concentration profiles by electron microprobe analysis in the cement stone sample as a function of time and distance from phase boundary were carried out. These data have been integrated into a theoretical model using finite difference techniques to establish an improved basis for longterm predictions /9/. A comparison between measured and calculated element concentration profiles is shown in Fig. 7.

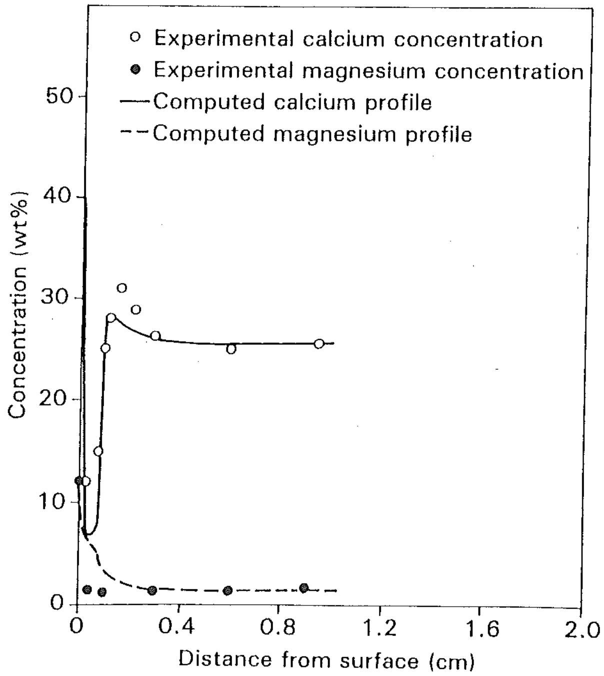


Fig. 7 Comparison between experimental and computed calcium and magnesium concentration profiles of a slag cement specimen corroded in quinary brine for 24 weeks at 40°C.

To investigate the influence of the conditioning process itself (homogenity, crack formation) on the leach behaviour and to verify the relation between laboratory and full scale samples, leach experiments with inactive 200-l and 400-l- samples were carried out at NUKEM and KfK. For both investigations the products contained about 10 wt.% salts and $CsNO_3$ as an inactive tracer was added. Samples of each waste form were prepared, using an in-drum planetary mixer or a continuous mixing system.

Fig. 8 shows the time dependence for the full scale and laboratory samples, produced at KfK.

Each sample had a volume of 160 l (w/c ratio 0.44, salt content 9.2 wt.%, inactive $CsNO_3$ content 0.9 weight%) and the amount of leachant used was 230 l. The experiments were performed at 40°C without changing the leachant. After certain periods the leachant was stirred and samples (0.5 l) were taken for analysis.

The results show no significant difference between the Cs leaching from the full and laboratory scale samples for the 1 year period.

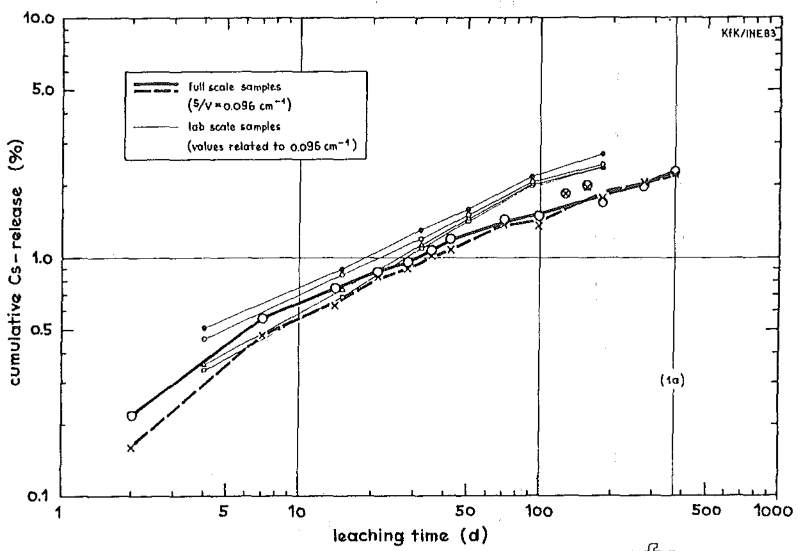


Fig. 8 Time dependence of Cs-release from full scale and laboratory cemented waste forms in quinary brine at 40° C

FUTURE ACTIVITIES

For long term considerations especially the release of actinides has to be investigated. The release is determined by two essential values, the kinetic of the activity release and the distribution of the activity between the solid and the liquid phase which has to be considered in a closed system. The establishment of the equillibrium depends e.g. on the volume ratio of the sample and the leachant, on the initial activity in the waste form and on the solubility of the nuclide compounds (oxides, silicate phases).

To determine the equillibrium distribution for Pu and Am experiments using samples with a high specific surface (to simulate a matrix corrosion) in excess leachant were performed. The investigations were started using Pu and Am doped samples as well as real samples from the KfK waste treatment facility.

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DISPOSAL STRATEGIES FOR RADIOACTIVE WASTE - EXPERIENCE IN THE FEDERAL REPUBLIC OF GERMANY

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1. Abstract

In the paper, a survey is given on the situation of nuclear technology in the Federal Republic of Germany (FRG) with regard to management and disposal of radioactive waste. Factors to be considered and implementation of disposal programs are briefly described.

2. Current Practice

In the Federal Republic of Germany, research on development activities on the field of the peaceful use of nuclear power began in 1956 with the foundation of the first nuclear research centres at Jülich and Karlsruhe, followed by other research centres not much later. Electricity generation by nuclear power began in 1961.

In 1986 nuclear power plants with an electric capacity of about some 18.500 MW are operational contributing some 35 per cent to the total public electricity generation. Additionally nuclear power plants with an electric capacity of about 5400 MW are in construction. According to the utilities planning, nuclear power plants with a total electric capacity of approximately 28.000 MW may be installed by the year 2000. As the spent fuel arising per 1200 MW_{el} and year amounts to some 30 tons heavy metal, this would lead to a spent fuel arising of some 600 tons heavy metal (HM) per year.

In addition, the use of nuclear power and nuclear activities in general originates radioactive wastes which in the FRG amounted to some 25.000 m^3 of conditioned waste and 7000 m^3 of unconditioned waste by the end of 1984, mostly composed of low and medium level waste (with negligible heat generation), but also of some 180 m^3 of heat generating conditioned waste and some 50 m^3 of high level liquid waste from reprocessing of spent fuel, being all these wastes stored in so-called engineering storage buildings. Till the year 2000, a total amount of about 240.000 m^3 of conditioned waste with negligible heat generation may be expected, and some 1000 m^3 of heat generating conditioned waste, including about 600 m^3 of vitrified high level waste from reprocessing.

Virtually from the beginning of nuclear science and power development, radioactive waste and spent fuel management was a point of concern in the FRG. This led to extensive research and development (R&D) activities in the various nuclear research centres, to the participation in the reprocessing project EUROCHEMIC in Belgium and to the operation of both a pilot disposal facility in a salt mine (ASSE) since 1968 and a pilot reprocessing facility at Karlsruhe (WAK) since 1971.

For the management of spent fuel in the FRG there exists a licensed capacity of some 4.700 tons in nuclear power plants and of 1500 tons in the away-from-reactor (AFR) storage facility at Gorleben - blocked by legal proceedings for the moment - where the spent fuel elements will be stored in casks ("dry storage"). At the experimental reprocessing plant at the Karlsruhe Nuclear Research Centre, there have been processed about 160 tons of spent oxide fuel since 1971. The experience gained with this facility forms an important basis for the planning of a larger facility, like the experience gained in the internatinal EUROCHEMIC reprocessing plant in the sixties and seventies.

The operators of nuclear power plants in the FRG have concluded contracts for the storage and reprocessing of spent fuel elements with foreign partners, namely in France and in Great Britain, to date about a total of some 4000 tons HM, from which about 550 tons HM were reprocessed by the end of 1985. Provisions for the spent fuel management of the experimental and prototype reactors High Temperature Reactor (HTR) and Fast Breeder Reactor (FBR) types (AVR, THTR-300, KNK, SNR-300, respectively) have been taken: HTR-fuel (graphit coated spherical fuel elements) is stored in casks for later direct disposal in the geological repository; FBR fuel is stored at the reactors and is planned to be reprocessed in France.

The intermediate storage of radioactive waste takes place at present on the sites of the nuclear power plants in the nuclear research centres, in industrial firms, and in the Federal States collection facilities.

The experimental reprocessing plant in Karlsruhe has a storage capacity of approximately 130 m^3 for high level radioactive liquid wastes. Around 50 m^3 are currently being stored there.

Low and medium level radioactive wastes are conditioned in nuclear power plants, in nuclear research centres and on the premises of some other waste producers.

3. Future Plans

Actual planning of the utilities calls for an electric nuclear capacity of about 28.000 MW_{el} in the year 2000. This indicates that about 10.000 tons HM of spent fuel would have arisen by the end of this century.

To manage these quantities and the radioactive waste arisings related to nuclear power and nuclear activities in general, the following activities are planned:

Industry

- Reprocessing of spent fuel in foreign countries, based on the existing contracts.

- Construction of a AFR storage facility with a capacity of 1500 tons HM at the city of Ahaus, Western part of the FRG.

- Construction of a demonstration reprocessing plant with a capacity of 350 tons HM per year (2 tons HM per day) to be sited at Wackersdorf (Bavaria). The plant includes a receiving facility for spent fuel (with a capacity of 1500 tons HM) and a storage facility for HLW glass blocks.

- Construction of a pilot conditioning plant for spent fuel at the site of the Gorleben interim storage facility.

- Extension of thermal recycling of uranium and plutonium in LWR, including recycling of fissionable material recovered from reprocessing of German fuel abroad and all Pu not needed for FBR fuelling.

- Extension of storage capacities for low - and medium - level waste (LLW and MLW), both at-reactor and away-from-reactor, taking into consideration the wastes from reprocessing abroad.

Government

While governmental responsibility is limited to disposal and safekeeping of waste, some R&D activities are sponsored that refer to safety questions of dry interim storage of spent fuel, reprocessing, waste conditioning and transportation.

Further activities sponsored by government refer to questions of direct disposal of spent fuel.

The most important task of Federal Government concerning the management of radioactive residues resulting from nuclear activities is the safekeeping and disposal of those radioactive residues:

- R&D activities on the field of disposal of radioactive waste are concentrated in the former salt mine ASSE, where more than 40.000 m^3 of low and medium level waste have been disposed of from 1968 to 1978, and on the former iron ore mine Konrad, both in Northern Germany. These R&D works are supported by activities in research centres and federal institutes.

- The suitability of the Konrad mine for disposal of wastes with negligible heat generation and wastes from the decommissioning of nuclear installations is being determined in the course of the current licensing procedure, a license being expected toward end of the eighties.

- An extensive exploration program has been performed since 1979 in the Gorleben salt dome to find out its suitability above all for disposal of heat generating waste like HLW glass blocks or spent fuel canisters. Excavation of two shafts for an exploration mine has begun and a judgement about the suitability of the salt dome is expected for the mid nineties.

- In addition to the R&D activities on disposal mentioned above, investigation continues on the possibilities of disposal in solid rock, partly in a Swiss-German cooperation, and on the possibilities of disposal of special radioactive wastes containing tritium, carbon 14, krypton 85 and iodine 129.

4. Institutional Framework - Reponsibilities and Financial Provisions

Spent fuel management and the management of all kinds of radioactive waste in the Federal Republic of Germany has been summarized under the designation "Entsorgung" (which might be translated with "relieving") and which means the contrary of "providing" or "supplying with", and is defined as the appropriate and safe conveyance, treatment - e.g. reprocessing - storage and disposal of radioactive residues coming out from the use of nuclear power and radioactive isotopes.

Bases of the policy of spent fuel and radioactive waste management in the FRG are the Atomic Energy Act and the so-called "Entsorgungs-concept" or "back-end - of - the - fuel - cycle-concept", the latter confirmed by the "Resolution of the Heads of Government of Federation and Federal States relating to the Entsorgung of Nuclear Power Plants" dated 28th September 1979. Pursuant to the Atomic Energy Act, anyone who produces radioactive residues shall make provision to assure that these:

- are recycled without harmful effects, or
- are disposed of as radioactive wastes in an orderly manner insofar as utilization is not technically possible, is not economically justified or is incompatible with the protective purpose of the Atomic Energy Act.

In accordance with this, in the Federal Republic of Germany, reprocessing of spent fuel elements with recycling of usable nuclear fuel materials and ultimate storage of reprocessing wastes has to be considered, the common way of "Entsorgung" of nuclear power plants.

The Entsorgungs-concept comprises the following steps:

1) Interim storage and treatment (i.e. reprocessing) of the spent fuel elements.
2) Development of direct disposal techniques without reprocessing.
3) Conditioning, interim storage and disposal of radioactive wastes.

The Atomic Energy Act allocates certain tasks to the operators of nuclear facilities, the Federal States and the Federation with reference to "Entsorgung".

Applying the "polluter pays" principle, it is the duty of the operators to provide for:

- the intermediate storage of spent fuel elements;
- the reprocessing of spent fuel elements including recycling of the fissile material;
- the conditioning of the radioactive wastes; and
- the intermediate storage of the radioactive wastes insofar as these are not delivered to Federal States' collection facilities.

The operator has the duty to demonstrate the provision for the "Entsorgung" and thereby, among other things, to prove that the safe storage of the spent fuel elements is always assured in advance for an operating period of 6 years as from the commissioning of the nuclear power plant.

The Federal States are obliged to erect Federal States' collection facilities for the intermediate storage of the radioactive waste occuring in their area, if such wastes result from the application of radioisotopes in industry, research and medicine.

The Federation, that is the Federal Government, is obliged to install facilities for the safekeeping and disposal of radioactive wastes. In accordance with the Atomic Energy Act, this task is performed by the Federal Agency "Physikalisch-Technische Bundesanstalt (PTB)" at Braunschweig. This institution forms part of the portfolio of the Federal Minister of Economics but, in this sector, is subject to the expert supervision of the Federal Minister for Environment, Nature Protection and Reactor Safety, (formerly to the supervision of the Federal Minister of the Interior). The PTB avails itsself of the cooperation of the German Company for the Contruction and Operation of Final Disposal Facilities for Waste (DBE), being the majority of the shareholders federal controlled companies.

With reference to the facilities for "Entsorgung" of the Federation and the Federal States, fees can be collected from those liable to deliver conditioned radioactive wastes in accordance with the "polluter pays" principle pursuant to the Atomic Energy Act. Prepayments for later contributions are collected for the facilities of the Federation on the basis of a decree issued in 1982. The costs incurred by the Federal Government in this connection are reimbursed annually since 1982 from waste producers corresponding to their estimated disposal requirements. Actually, 97 per cent of the cost is borne by the German Reprocessing Company and by the public utilities engaged in nuclear power. This means, that these costs are finally paid by the electricity consumer. The rest of 3 per cent is borne by the other waste producers including users of nuclides in medicine, research and industry. Therefore, the installation of future disposal facilities is payed by the users of nuclear technology already now.

5. Disposal Activities in the FRG

As already mentioned, from the beginning of nuclear techniques development in the FRG, there was also begun research and development on the field of spent fuel management and management of radioactive waste, including activities concerning ultimate disposal of radioactive wastes.

While R&D activities for waste conditioning were concentrated mainly in the Nuclear Research Centres of Karlsruhe and Jülich, completed by activities of the nuclear industry, and by projects directly induced by the Federal Government and in the frame of R&D programmes of the European Community, the R&D for disposal of radioactive waste was concentrated in the Institute for Geologic Disposal (IfT) which belongs to the Radiological and Environmental Research Centre (GSF) at Munich, completed by activities of other institutions like the Federal Agency for Geologic Sciences and Raw Materials (BGR), the already mentioned Federal Agency PTB, and KfK.

Facility ASSE

From 1967 till 1978 the former salt mine ASSE near Braunschweig was operated as disposal facility for the demonstration of disposal techniques for low level and medium level radioactive wastes. During this period some 125.000 barrels of low level waste (42.000 m^3) and 1.300 barrels of medium level waste (260 m^3) were disposed of. Further on, research and development work for the disposal of radioactive wastes in salt formations is primarily performed in this mine. Disposal experiments with high active, heat generating glass blocks will be performed still in the eighties. These blocks will be removed at the end of experiments. In addition, checks are carried out to see whether ASSE can be used for the Entsorgung of radioactive wastes in the future.

Facility Konrad

The former iron mine Konrad near Salzgitter (in the Braunschweig area) is planned for the final disposal of low level radioactive wastes and wastes from the decommissioning of nuclear installations. Its suitability was determined in the course of a detailed examination performed by the Radiological and Environmental Research Centre GSF (Gesellschaft für Strahlen- und Umweltforschung).

On the basis of this suitability report, the Federal Agency PTB submitted an application for the issue of a license to the Government of the State of Lower Saxony in 1982. The license is expected to be issued still in the eighties. It is assumed that disposal in the mine Konrad can commence about 1990.

Facility Gorleben

According to current plans, the planned disposal facility in the salt dome Gorleben, in the North-Eastern region of the Federal Republic is the only repository in which high level radioactive heat-producing wastes are to be stored in addition to low and medium radioactive wastes.

The site exploration programme, comprising a hydrogeological drilling programme, salt level drillings and deep drillings began in 1979 and has been completed. The sinking of two exploration shafts began in summer 1984. Summarizing and examining all the results obtained to the date in the site examination, the PTB and the Reactor Safety Commission (RSK) came to the conclusion that to date there were not provided any results which would question the suitability of the salt dome of Gorleben for the disposal of radioactive wastes of diverse origin, including high level radioactive waste.

In order to demonstrate the suitability of the disposal facility Gorleben in the licensing procedure, it is essential to carry out an underground exploration. The German Company for the Construction and Operation of Disposal Facilities for Waste DBE is commissioned with the fast performance of the work. The underground exploration is expected to supply important findings by the end of the eighties and that it will be possible to give a final verdict on the suitability of the salt dome as a disposal facility for radioactive waste at the beginning of the nineties.

Disposal capacity

If the planned final disposal projects are realized, all conditioned waste occurring up to the year 2000 could be disposed of. No bottlenecks are to be expected after this date either.

Direct disposal of spent fuel

Direct disposal of spent fuel is foreseen for special fuel elements not suitable for reprocessing, e.g. HTR fuel or fuel elements from research or prototype reactors. Whether this technology will be acceptable for LWR fuel, too, will depend on the results of technological development and finally on the adaptation of the Atomic Energy Act which actually prescribes recycling, i.e. reprocessing.

Further Research work on disposal

Disposal in solid rock

In addition to disposal in salt formations, the Federal Government is checking the suitablility of solid rock. Granite is primarily of interest in this case. Development work is being performed on examination methods, which are suitable for solid rock, e.g. granite, in the mine Konrad taking the ore formations there as an example. Important research work on granite is being executed in the frame of a bilateral German/Swiss cooperation. Furthermore, knowledge gained in the frame of research work performed by the European Communities is also at the disposal of the Federal Government.

Radioactive special wastes

Radioactive wastes mainly consisting of separated tritium, carbon 14, krypton 85, iodine 129 or radium are termed special wastes because these radionuclides are volatile, form volatile compounds or decay to produce volatile radioactive daughters. In the course of research work performed, conditioning processes, which can ensure safe disposal, are also developed for these wastes.

Dumping of radioactive wastes at sea

Pursuant to the German ratification law on the "Convention for the Prevention of Marine Pollution as the Result of the Dumping of Wastes by Ships and Aircrafts" dated February 11, 1977, permission to dump any kind of waste at sea may only be granted if disposal on land is impossible without impairing the public health or can only be implemented with an unreasonably high expenditure and if no disadvantageous change in the quality of the sea water is to be feared as a result of the dumping.

As presented above, according to the present state of knowledge it is possible to dispose of radioactive wastes (and special wastes) on land without impairing the public good and without an unreasonably high expenditure. For this reason, the Federal Government does not see any need to discuss the question of the dumping of radioactive wastes into the sea at present. The futher prerequisite for permission, namely that the dumping at sea must not make one fear a disadvantageous change in the quality of the sea water, is therefore of less importance for the decision.

For reasons of research policy, the Federal Government is, nevertheless, involved in pertinent international investigations. Furthermore, it takes part in the international surveillance procedure which is set down in the OECD council resolution for the creation of a multilateral consultation and surveillance system for the sea dumping of radioactive wastes, dated July 22, 1977.

Shutdown and decommissioning of nuclear facilities

The obligation to dispose of radioactive wastes also covers radioactive parts from shutdown nuclear facilities. Shutdown and decommissioning of the plant are the duty of the operator or owner of the plant.

The research reactors FR 2 and MZFR (Karlsruhe) and FRN (Neuherberg near Munich), the prototype nuclear power plant Niederaichbach/Bavaria (KKN) and the nuclear power plants Lingen/Northrhine-Westfalia (KWL) and Gundremmingen/Bavaria (KRB-1) have finally stopped operation and are avaiting decommissioning.

After removal of the reactor and decontamination and dismantling of the other nuclear systems, the nuclear ship "Otto Hahn", which now has the status of a conventional ship, has been released from supervision according to the Atomic Energy Act.

The complete decommissioning of a nuclear power plant is to be demonstrated for the first time in the Federal Republic of Germany using the plant Niederaichbach (KKN). The demolition plans are essentially completed.

It is planned that decommissioning wastes will be disposed of in the former Konrad iron mine.

6. Factors influencing spent fuel/radioactive waste management and disposal policy

- Current spent fuel/radioactive waste management policy is based on political decisions and ordinances issued between 1976 and 1979 and mentioned in chapter 4. Since then, the operation licenses of nuclear power plants are legally linked to the proof of the safe management of spent fuel always 6 years in advance, and to progress of the realisation of the back end of the fuel cycle concept ("Entsorgung"). As the by far largest producers of radioactive waste are the nuclear power plants and the fuel cycle facilities linked hereto, the safe management of radioactive wastes including future possibilities of waste disposal has become a crucial condition for the further use of nuclear energy in the FRG.
  This, on the one side, led to one of the possibly most advanced disposal programs in the world, on the other side, to growing political problems relating to the realization of the "Entsorgung", as the opponents to nuclear activities have detected just this link of the nuclear fuel cycle as possibility to stop the future development of the peaceful use of nuclear energy.

- Political discussion about the development of nuclear energy in the FRG and actions at the courts concerning many nuclear projects led to delays up to years in some cases, which caused a severe raising of the costs of nuclear installations. Additionally, safety standards required in the licensing procedures became enlarged, partly caused by the political irritation on the field of nuclear technologies, which gave rise to higher costs, too.

- The delay of projects by political reasons also concerns the use and development of disposal sites. Here the

special situation resulted, that the amendment of the Atomic Energy Act of 1976 demands public participation in the licensing procedure of disposal sites, too, like it had been the case already in the licensing of nuclear power plants and other nuclear facilities.
Therefore, the license for disposal of radioactive waste in the ASSE salt mine which expired in 1978 was not renewed automatically and political discussion since then impeded the disposal of low and medium level waste, so sucessfully demonstrated during 10 years.
There has also been some delay by growing concern in public and political opinion with regard to selection of a disposal site for future waste arisings, including heat generating high active waste, in the seventies. But after beginning of the exploration program at the salt dome near Gorleben, this project is well within the schedule of 1979. This also can be stated with regard to the former iron mine Konrad.

- Of course the remarkable reduction of nuclear capacity forecasts since the seventies has to be considered. While in the seventies a nuclear electricity production capacity of 40.000 to 50.000 MW by the year 2000 was foreseen, this figure was reduced step by step in the last years, to a forecast of some 25.000 to a maximum of may be 30.000 MW_{el} by the year 2000. There is not an immediate influence on spent fuel and radioactive waste management policy, but with this reduction the spent fuel storage capacities in operation or under construction probably will be sufficient - in addition to the existing reprocessing contracts with foreign countries and the planned reprocessing in the FRG - to manage all spent fuel arisings till the year 2000. This could mean a relief in the restraint to have to manage and dispose of the resulting radioactive wastes.

- There must also be taken into consideration in disposal strategies the fact that the reprocessing contracts with foreign countries include returning of the corresponding radioactive waste arisings to the FRG. This could be realized in the nineties at the earliest, after mutual agreement.

- A relatively new factor to be taken into account in disposal strategy is the development of conditioning techniques for all kind of spent fuel, not only from HTR pebble bed reactors, with the aim of direct disposal. Studies on consequences of this spent fuel management form to disposal techniques have been performed; the disposal technique itsself is to be developed in the coming years.

- Other factors of possible influence on disposal strategies are given by cooperation in international bodies, international agreements and joint R&D with foreign nations on this field.
  The FRG takes part in disposal related research activities in the frame of the so-called "indirect action on radioactive wastes" of the Commission of the European Communities.
  There exists a R&D cooperation on the field of radioactive waste management and disposal of the USA and the FRG, in the frame of a corresponding agreement. The cooperation on the field of hard rock disposal with Switzerland has been mentioned already.
  Finally, the FRG cooperates with international bodies on this field, in the frame of the European Community, the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD), and the Internatinal Atomic Energy Agency (IAEA).

As resumé it can be stated that international contacts and cooperation on this field are generally considered a valuable factor in development of disposal strategies.

- A fact that has to be taken into consideration is that all disposal activities in the FRG will take place in continental geologic repositories. This is of importance for example for the development of waste conditioning techniques or the waste treatment strategies in nuclear facilities, i.e. reprocessing plants. Of course an important aspect in this regard is the possibility of waste volume reduction by new conditioning methods.
- The question of safety of course is a crucial factor concerning the acceptability of disposal strategies, for political and licensing bodies as well as for the public. Safety analysis like those elaborated in the frame of the "Project Safety Studies Entsorgung" (PSE), can be of great help in this regard.

- Last but not least, a very important factor is the financial aspect. Although in the FRG, the Governmental Bodies are responsible for the installation of safekeeping and disposal facilities for radioactive wastes, the "polluter pays" principle is applied here, too. In accordance with the Atomic Energy Act, the erection of disposal facilities and disposal are financed by the waste producers, that is, finally by the user of nuclear energy or nuclear services.

BATAN's ACTIVITIES IN NUCLEAR SAFETY

ISMUNTOJO
SUHARNO

INDONESIA - GERMAN SEMINAR
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BATAN's ACTIVITIES IN NUCLEAR SAFETY

INTRODUCTION

The general activities in the Reactor Technology and Nuclear Energy which cover also Nuclear Safety are outlined in the BATAN's long Term R & D Programme in nuclear field with its objectives are :

- Safe, economic and reliable energy supplied by Nuclear Power Plant.
- Wide spread benefication of Nuclear Technique and Nuclear Technology.
- Safe and protected environment against conventional pollution and nuclear hazard.

And the basic programme related to the nuclear safety is :

- To investigate the material and component behaviour, and to contribute and partisipate in international Research and Development Programme.
- To contribute to the demontration and assurance of plant safety and reliability through experiment and research.

Therefore Nuclear Facilities (reactor and supporting laboratories) are built in Serpong included Engineering and Safety Laboratory. A facility to study reactor safety had also been installed in Bandung (Research Center for Nuclear Technique). Then the programme on Nuclear Safety should be established.

As goal of BATAN's long term programme on utilizing nuclear energy for electricity in Indonesia is to introduce nuclear power plant, where the safety aspects is the main consideration besides economical and political aspects. Presently BATAN has started to initiated some activities for studying Nuclear Power Plant in some aspects included safety aspect for facing and handling plant which have high reliability and high safety in its operation.

That goal acheivement should be support by improving and developing of technology, personnel capability and regulation through research activities.

Safety research will cover :

1. Research required for development of criteria for safety standard and safety inspection.

2. Research to improve safety of nuclear facilities and its components which must be introduced in to the design, fabrication, construction and operation.

The research programme is carried out on the international level and the possibility of implementation through international cooperation.

BACKGROUND OF NUCLEAR SAFETY ACTIVITIES

Several activities on nuclear safety assesment are explained here which intended as background of Nuclear Safety activity programme.

1. The first research reactor was commissioned in 1965, which located in Bandung. The reactor was TRIGA MARK TYPE made by General Atomic with 250 KWT capasity as nominal power. The advent of reactor initiated the study of reactor safety. The safety assesment was carried out in connection with research programm proposal as the utilization of reactor. Then the safety assesment was emphesized on reactor operation in longer time and on the up grading of reactor power up to 1000 KWT.

2. Reactor Kartini was the second research reactor and built in Yogyakarta. It used spent fuel of TRIGA MARK II REACTOR in Bandung, therefore the safety assesment on spent fuel transportation due to the criticality was carried out. This reactor was constructed by BATAN personnels and of course it gave as a good experience to the engineers and scientists and also gave the experience on the evaluating of safety aspects.

3. Regulations, safety inspections, monitoring including its procedures were developed by BATAN's Regulatory Body.

4. With the operating of TRIGA MARK II Reactor and Kartini Reactor, a project was initiated which was concentrated to study research reactor safety mainly for reactor operation procedure, core thermohydraulics core physics, and environmental monitoring, with the aim was to improve reactor operation safety. The project was started in the third period at five years development plan.

5. With the increasing of electricity demand in Indonesia, the possibility to introduce nuclear power plant was discussed in a seminar in 1968, then followed by a series seminar thereafter. The seminar concluded that nuclear power plant was the one of promising alternatives to supply electric energy demand. As a follow up of the conclussion, BATAN made a preliminary site selection in Java where several places were investigated and then decided one place for making detail examination. Then feasibility study has been carried out. The conclusion also motivated researchers to study technology of Nuclear Power Plant in various institutions within and outside BATAN. One of the study was held in Research Center for Nuclear Technique in Bandung to study safety of Nuclear Power Plant on thermohydraulic aspects. To suppot that purpose, a laboratory for thermohydraulic study was installed and some activities were performed.

6. With the decision to build a Multipurpose Reactor in Serpong, a very rare apportunity was existed due to the new design of the reactor. A few engineers and scientists were sent to joint with the designer group of supplier to partisipate and take part in design phase in connection with transfer of technology, where also included the safety group. Thereby experience in design, evaluation, construction and commissioning are gained during the execution of this project.

7. Along with the Multipurpose Reactor, several nuclear facilities are also built to support reactor, to provide facilities for doing activities related to the reactor utilization and to support the research on Nuclear Power Plant technology such as Fuel Technology and Nuclear Safety, etc.

8. In preparation to the introducing of Nuclear Power Plant in Indonesia where now is under assesment, BATAN has established a center to study technology of Reactor Safety. The fields which would be investigated are Reactor Protection System, Analysis and Reliability of Reactor System, Ergonomic of instrumentation and human equipment interaction, Accident Analysis, Testing of equipment, reactor component and material for reactor structure. These activities are supported by Engineering and Safety Laboratory which will be established in Serpong.

FACILITIES FOR NUCLEAR SAFETY ACTIVITIES

A. The existing facility :

NILO-1 Thermohydraulic Loop in Bandung.

B. The future facilities :

- Ramp test facility
- In-pile devices for irradiation
- Out of pile loops (general loop, primary loop and test rig)
- NDT equipment
- Mechanical testing machines

ACTIVITY PROGRAMME

1. Period 1986 - 1989

1.1 To continue experiments using the existing facility NILO-1 thermohydraulic loop to study heat transfer, thermohydraulic on steady state and transient condition, and to study two phase flow, etc.
The experiments are performed by simulation of fuel rod with a single heated rod test section at the Nuclear Power Plant specification of Light Water Reactor as well as Heavy Water Reactor.

1.2 To continue the previous work in safety assesment of TRIGA MARK REACTOR especially on the operation safety.

1.3 Performing safety assesment to the MPR-30, and by this experience the capability of personnel can be improved.

1.4 To construct and to install Engineering and Safety Laboratory.

2. Period 1989 - 1994

After the completion of several facilities for doing safety study, some activities which will be carried out are aotlined.

2.1 Activities on fuel element and material for reactor structure using irradiation facilities.

2.1.1 Using Ramp Test Facility, the study will be carried out for determination of the threshold values and mechanism for fuel failure due to Pellet Cladding Interaction to confirm the integrity of fuel during low and midle burn up of new fuel element and irradiated fuel element.

2.1.2 Subassembly fuel bundle test qualification for LWR type fuel element and HWR type fuel element using PWR/PHWR in-pile loop.

2.1.3 Testing of MTR type fuel element in the form of mini plate, to investigate burn up, heat generation, dimension changes.

2.1.4 Testing of single fuel pin to study heat desipation, changes of dimension, burn up, fission gas release.

2.1.5 Creep test under irradiation for material of reactor structure/reactor component to study creep behaviour.

2.2 Study on thermohydraulic of the power channel for LWR as well as PHWR with the simulation of heated rod assembly in steady state and transient condition using general loop. The study on small LOCA can also be carried out.

2.3 Study on water chemistry using primary loop, including corrosion study, and crud deposition.

2.4 Study on freeting corrosion/stress corrosion using test rig for stainless steel and zircalloy.

2.5 Dynamic fracture test of stainless steel and zircalloy. The objective is to study the foundamental problems of metallographic fracture mechanism related to fracture behaviour.

2.6 Study on inspection technique. The study will be stressed on the utilization of NDT equipment likes acoustic emission, eddy current unit, ultrasonic unit, x-ray to investigate defect, crack, crack propagation etc.

2.7 Testing of small components such as rotary seal, safety valve as reliability test.

2.8 Study on probabilistic risk assesment and the reliability on nuclear facilities. The objective is to determine risk by probabilistic risk assesment method within the permissible level. Risk Assesment must be developed where the result must be directly applied for improvement of design, operation, and it will contribute to the improvement of plant safety.

3. Period 1994-1999

If there is no major change in reactor technology, a similar programme will be conducted as continuation of previous years.

Nuclear Safety Research in the Federal Republic of Germany
Contribution to Licensing Process and Plant Performance

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Nuclear Safety and Waste Management
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4.3 Man/machine interaction

4.4 Risk and reliability

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6. Summary and outlook

1. Introduction

In this presentation an overview is given on the current programme of reactor safety research in the Federal Republic of Germany. For a number of selected topics the development of the research work and the contribution of the results to licensing and plant performance is shown and an outlook of future demands on reactor safety research is given.

The presentation concentrates on the research into reactor safety sponsored by the BMFT (Ministry for Research and Technology). Except for the joint ventures between BMFT and industry, the research conducted directly by industry in its continuous effort to further develop reactor safety will not be covered here.

The systematic approach to reactor safety research in Germany dates back as far as 1970 when a programme was set up by the predecessor of todays BMFT-Ministry of Research and Technology. The research programme was a natural consequence of the growing experience in the field of reactor technology in Germany, which had started with plants built under American licenses (AEG-GE and Siemens-Westinghouse) and safety evaluations based on American research and development results.

As German industry began with their own technical developments, modifications of the American systems first, leading to complete new designs later, and authorities and experts gained more and more experience in the safety area, the neccessity for national research into reactor safety became obvious. The new designs and the safety requirements, some of which went beyond US-practice, posed questions which could not all be answered on the basis of foreign research alone.

Today, in the Federal Republic of Germany there are 10 pressurized water reactors (PWR) and 7 boiling water reactors in operation. 3 more PWR are under construction, 1 PWR and one prototyp gas cooled high-temperature (THTR 300) are in the commissioning phase. A small gas cooled high temperature reactor (AVR) has been in operation since 1967. The construction of the prototype fast breeder reactor (SNR 300) is almost completed; a small fast breeder (KNK II) being in operating since 1973.

2. The objectives of the BMFT reactor safety research programme

The utilization of nuclear energy in a country as densely populated as the Federal Republic of Germany requires high safety standards. Consequently the protection of man and environment against release of radioactive materials is written down in the German Atomic Energy Act. From this principle aim of reactor safety, the objectives of the BMFT programme on reactor safety research are derived, so that safety research contributes

- to keeping the residual risk low in comparison to other risks of civilisation, even under growing use of nuclear energy, and to the further development of safety technology.

The research work within the BMFT-programme is aimed at

- a continuous extension of the knowledge of potential causes and sequences of accidents;
- a continuous further development of the methods used for a realistic assessment of safety;
- the analysis and evaluation of safety margins; and
- the further development and optimization of safety technology.

3. The role of research within German reactor safety

Before dealing in somewhat more detail with the technical questions being pursued within the main research areas, it might be worthwhile to identify the role of this research work within German reactor safety as a whole. Its task is to further develop the status of science and technology and to provide the sound basis of knowledge and expertise to be used by all institutions contributing to reactor safety.

While decisions regarding licensing and supervision of plants in operation are based on the consensus state of science and technology at a given time - Mr Philip will talk about that later - the further development of that status in the safety area is a matter of the BMFT research. The research is pursued according to a continuously monitored and updated research programme addressing light water, fast breeder and high temperature reactor plants.

Consequently the RSR-programme is not a licensing programme, the results of which are preconditions for decisions to be drawn in licensing procedures and RSR is not conducted because of insufficient safety of the nuclear technology applied.

A considerable part of the reactor safety research, is being executed by the nuclear research centre at Karlsruhe and to a lesser extent by the centres at Jülich and Geesthacht.

The other research work is performed by universities and other research institutions, GRS, TÜV, independent engineers and by industry. Beside it's task as a research organisation, GRS is assisting the BMFT in the coordination and fund administration of reactor safety research. The funding is done mainly by direct research contracts or by sponsoring research work undertaken by universities or industry.

The results obtained by that work are distributed inside of Germany to all institutions concerned with reactor safety so that a broad based consensus can be achieved on any topic. These are federal and individual state authorities, safety experts, industry and the public, which, as discussed in the first part of this seminar, is often strongly engaged in discussions concerning the safety of large technical systems.

Especially for the support of international cooperation also brief annual reports are published in English.

4. The main research areas

In accordance with the situation of nuclear energy in Germany, reactor safety research has been concentrated mainly on LWR.

The research programme reflects the German safety concept, aiming for safe operation, control of incidents and provisions in the field of residual risk, with highest priority attached to the prevention of accidents.

Presently the research programme concists of 4 main areas:

- Component safety and quality assurance
- transient analysis and accident sequences
- man-machine interaction
- risk and reliability.

In the following, the 4 main research areas will be discussed in sequence. Reference will be made to their development in time, also showing how previous achievements caused changes in the priorities given to various topics.

4.1 Component safety and quality assurance

Part of this research area are the investigations into the integrity of the primary circuit and its components, i.e. reactor pressure vessel, pressurizer, steam generator and interconnecting pressure pipes. The behaviour of real components was investigated under loadings, like pressure and temperature, water chemistry and radiation, to be expected during normal operation and accidents. Real components means, that components or their materials were investigated including possible quality reductions by deviations from specified compositions, by micro-cracks, non-metallic inclusions and material modifications caused by welding or irradiation. The first slide shows one example of many experiments investigating the influence of flaws on the burst pressure of a vessel.

The results of this research provided a very good understanding of quality reducing effects from component production concerning the choice of material, the forging, welding and annealing processes. E.g. the steel 20 MnMoNi 55 is the preferred material because it gives high strength, ductile behaviour and reasonably constant material properties even for higher wall thickness. For welding e.g. welding rods containing copper are to be avoided because of possible radiation embrittlement.

Similarly the behaviour under operating loads has been investigated and solutions worked out, e.g. a larger gap of water to limit the neutron flux to the reactor pressure vessel. Thermoshock has been discussed internationally to great extent. Our experiments show that very many (3000) temperature cycles are possible without crack initiation. Nevertheless new constructive details were chosen to further reduce the loading of important components.

Closely connected to this line of research is the further development of non destructive examination (NDE) techniques, with the aim of a total volumetric testing ability of primary circuit components with respect to all relevant faults, including their location and description.

The techniques applied today for quality assurance during construction and operation are mainly ultrasonic (US) inspection and eddy current testing. More recently new developments have been included, using the potentials of modern small computers for more sophisticated analysis of ultrasonic signals in order to improve fault description. Examples are ALOK (Amplituden Laufzeit Ortskurven), where the time of flight of the US-signal is evaluated, and the American Synthetic aperture focusing technique (SAFT), where high resolution is obtained by signal manipulation of comparatively low resolution US beams.

For application under adverse conditions like high radiation levels, remote control techniques are being improved to allow non destructive testing by automatic manipulator systems.

The central pole manipulator,for excample, allows automatic evaluation of the findings in the reactor pressure vessel and a reproducability of sensor positioning of ± 3 mm, which is important for comparison of signal mappings to detect any changes between inspections.

Today we can state that a sufficient detectability of safety relevant faults has been achieved, a good status in their description and very useful remote control techniques.

This research is actually a very convincing example on the contribution from safety research to the licensing process.

One of the most important application of the results was the formulation of the "Basis Safety Concept". In this, detailed procedures are laid out for production and quality assurance of components with safety relevance. If adhered to, the Leak Before Break research results show that guillotine breaks of primary circuit components can be excluded for design considerations of the primary circuit. The most obvious consequence of this was, that expensive technical measures against pipe whip are no longer required.

Even though considerable progress has been made over the years, experimental and theoretical investigations are being continued into the description and evaluation of alterations of material properties as a function of operating parameters, e.g. the influence of fatigue, irradiation, corrosion, thermal shock on material properties with the aim of early prediction of possible component failures, also for long time operation.

Further investigations are also required concerning the transfer of results from laboratory investigations to real components, concerning the failure modes of real components, fault propagation in steam generators and a further assurance of the Leak Before Break criterion for a broader range of parameters.

In the field of nondestructive testing, further improvements are aimed at in the detection sensitivity and reliability, in particular under difficult conditions like complicated geometries, crack fields under pressure tensions and in cladding surfaces. Testing techniques for coarse structure materials like austenits are also under development.

4.2 Transient analysis and accident sequences

The structure of this chapter is given in figure 1.
At the beginning of this section, I'd briefly like to mention the research into the effects of external hazards. In this field many results have been obtained in recent years, so that now efforts at a much reduced scale suffice for the few remaining questions concerned with earthquake loading.

The external hazards under consideration were air plane crash, gas cloud explosion and earthquakes. They have been considered in such detail because they can initiate commom mode failures, so that the design advantages of redundancy and diversity may be considerably reduced in case of their occurance. Therefore, German nuclear plants are designed against these events.

The main investigations concerning aircraft crash were large scale experiments at a military testing site at Meppen, where 6 m long deformable projectiles crashed with 230 m/s onto 6 m x 6 m slabs of reinforced concrete. Figure 2 shows the test site, where in all 22 of these tests have been performed.

Accompanying analytical efforts, led to a very good description of the nonlinear response of reinforced concrete under impulsive loading, the results confirmed the design method and were incorporated into the draft of a design-rule.

The earthquake research field spans from investigation of the seismological parameters like duration of earthquakes, frequency contents of excitation, maximum acceleration, to the response of buildings and finally to the response of components and their pipes in the plant.

Of course, the frequency of occurance of earthquakes in Germany and their magnitude are very low in comparison. Nevertheless some research has been devoted to quantify the safety margins which are obvious from experience. Today building and machinery responses are well understood for low and medium excitations as could be shown by comparison between calculations and large scale experiments, particulary at the HDR plant.

The HDR-investigations are presently extended to extreme loadings, forcing non-linear material behaviour of the structures.

Let me briefly introduce this very special experimental research facility, the HDR. The HDR is a decommissioned superheated BWR, which had 100 MW_{th} thermal power, started operation in 1970 and was shut down by the end of 1971 because of fuel element problems. The containment building hight is 52 m, its inner diameter 20 m. Since 1975 it is being used for reactor safety research and it enables, because of its size, tests in a scale considerably larger than other facilities allow and with real objects (pressure vessel, piping, pumps etc.).
This is an important facility for the investigations of result transfer to large dimensions as can be seen from the comparison of test facilities to real containments shown in the figure 3.
The investigations, which have attracted considerable interest and also international cooperation, are grouped under the following headlines:

Nondestructive and destructive testing
Loadings and failure modes
Fluid- and thermodynamics
Structural dynamics
Special investigations, like fire research

Coming back to the topic of transient analysis and accident sequences, I'd like to continue with the detailed investigations concerning the plant behaviour under emergency core cooling and transient conditions.

Research on emergency core cooling has been conducted for a long time. At first separate effects were investigated, like heat transfer from the core to the cooling fluid and the fuel element behaviour under abnormal conditions (the large break 2F rupture being of particular interest because of the licensing requirements), flow distributions in various phases of the accidents. In sequel the interrelation of the separate effects received much attention, including the whole loop to describe the core cooling situation. This is reflected in the experimental facilities like LOBI (Loop Blowdown Investigation at the Joint Research Centre at Ispra, Italy) and PKL (Primärkreislauf, Primary circuit) of KWU, capable of investigating the pressure ranges 150 bar to 10 bar (blow down) and 40 bar to 0 bar (refill, reflood), respectively.

As an example the PKL facility is shown in figure 4, which simulates a 4 loop pressurized water reactor by using three loops, one of them having double capacity. The facility offers the genuine elevation scale, the volume however is reduced by a factor of 130. Its main application is for systems effects tests to look for the interplay between components and for application of the results for code verification.

The detailed investigations concerning the emergency core cooling (ECC) and fuel behaviour under these circumstances, including the fluid/structure interaction at the beginning of blow down, have confirmed the existing design. Experiments at the LOBI integral test facility (Volume scaled 1:700) for the blow down phase showed the effectiveness of the German cooling concept, using injection into both hot and cold legs of the primary circuit. The investigations concerning large breaks have been complemented by the analysis of experiments at the nuclear LOFT reactor, scaled 1:50 as well as refill experiments at the PKL facility. All investigations led as a result of loss of coolant to maximum fuel rod temperatures below the design limit of $1200^{\circ}C$.

With the investigation of large scale effects and their impact on emergency core cooling in a current large scale experiment, the major part of the research relating to the loss of coolant through a large break will essentially be completed. This is part of the international 2D/3D Emergency Core Cooling Project carried out in a joint effort by the Federal Republic of Germany, Japan and the United States. Japan is investigating processes inside the reactor core. In Germany the experiments concerning the processes in the upper plenum of the reactor pressure vessel are carried out at the UPTF shown in the figure 5. The United States have supplied the data collection system for the German experimental facility as well as the advanced instrumentation needed and made available the sophisticated computer code TRAC. TRAC and the German code FLUT, separately developed within this project are being verified using the experimental data. Recently, the first three experiments on the German test stand were completed successfully.

For small leaks, the main problem was the adequate removal of energy from the primary circuit. The research results have shown that for all conditions of the primary circuit - even for interrupted natural circulation and in the presence of non-condensible gases - sufficient heat removal is ensured. The effectiveness of heat removal from the primary loop by means of cooling down on the secondary side at a rate of 100K/h could be demonstrated both at the LOBI and PKL facilities.

More recently the emphasis has been shifted to smaller deviations from normal plant operations, the transients. Work regarding transients includes the components which help to avoid negative consequences, e.g. armatures of the primary circuit, steam generators, pressurizer and secondary side components. The analyses of the interplay of various components and systems are carried out, both experimentally, as well as analytically.

The PKL experimental loop is being modified (PKL III) to investigate possible events which could affect the primary circuit or its components if, in addition to the transient, the failure of a safety relevant component would occur. It will be used to optimize recovery procedures designed so far.

The experimental results will be used to further improve the analytical description of transients.

This analytical description of the whole plant behaviour under a wide range of conditions is at the centre of attention in the Analyse-Simulator project. The aim is a comprehensive package of computer codes, describing the physical behaviour of the plant like DRUFAN, ALMOD or the American Code TRAC as well as the behaviour of various plant systems and their interactions.

The simulation of plant systems is to include the most relevant failure modes of these systems as well as provisions to simulate operator interventions.

It is hoped, that the Analysesimulator, by providing interactive facilities to the user of the code package, will greatly enhance the capabilities for analyses of abnormal events, where automatically acting protective systems and possible operator interventions are taken into account as well as todays best thermal-hydraulic codes for a description of the physical phenomena.

In parallel to these investigations into small deviations from normal operating conditions and into accident control by emergency core cooling, very early research has been conducted beyond the design basis looking into accident courses where total failure of ECC system is postulated. Such investigations form the scientific basis for risk analytical work, which has to include also very low probability events.

The phenomena after total ECCS failure are core heat up and melt, dropping to the bottom of the pressure vessel, its subsequent melt through and melt concrete interaction in the containment. The accompanying effects of Hydrogen-formation, steam explosion, fission product release and their transport inside and eventually outside the containment have been investigated.

Today the core melt down process is reasonably well understood, being described by the codes like KESS. Steam explosions powerful enough to destroy the reactor pressure vessel or the containment are considered practically impossible.

Large scale experiments at the BETA facility on melt-concrete interaction have shown, that this interaction does not lead to any essential further release of active fission product aerosols from the melt and that the initially rapid penetration of the melt into the concrete involves a considerable temperature decrease leading to a lower penetration velocity (approx 1 cm/h at ca. 1300 - 1500 °C). Figure 6 shows the results of BETA in comparison to earlier assumptions. The penetration behaviour and the release of H_2, CO and CO_2 can now be described with good accuracy, in the codes WECHSL and KAVERN, the data being of importance in the risk assessment and accident management.

This is also true for the results of the DEMONA-project, which showed by large scale experiments that the concentration of fission product aerosoles in the containment atmosphere is reduced by a factor of about 10 000 within a short period of time (7-30 h). In particular for the radiologically important iodine, detailed chemical and physical investigations as well as the TMI experience have shown, that most of it is in the soluble form of CsJ and only about 1 % of the core inventory in the form of easily volutile iodine.

The DEMONA results are being applied to verify codes like NAUA and FIPLOC.

The pressure rise within the containment because of sump water evaporation and melt/concrete interaction can be described quite well by analytical means. This is shown in the transparency, where the pressure in the containment is shown as a function of time for the low pressure (large break LOCA) sequence, a particular small leak and the high pressure sequence, all of them resulting in containment overpressurization after 4 to 5 days. Consequently means for depressurization of the containment are being discussed in Germany.

H_2 and CO can be generated in the vessel by the exotherm zirkonium-steam reaction and during the core melt interaction, when water is evaporated from the concrete and travels through the melt. Regarding the behaviour of these inflammable gases further investigations are in progress, looking at the distribution within the containment and possible burning modes.

From the point of view of controling even such sequences, the questions of degraded core cooling are also of interest: The behaviour of an inadequately cooled core, e.g. if ECC is only partly available, or the possibilities of bringing a degraded core back to thermal stability.

This area is part of the accident management which deals with the question, how available operational systems may be used to keep the consequence of degraded core cooling as low as possible, that will receive even more attention in the future.

4.3 Man-Machine Interaction

The running of nuclear power plants by the operators and their responses to perturbations are a factor of outmost importance to safety. This judgement is strongly supported by probabilistic analysis as well as international operating experience.

The human factor is to a large extent already taken into account in the design of our plants, I only briefly remind you of the 30 minute time span given to the operator in German plants by the built in safety features. This means that in more serious disturbances the operator can diagnose and analyse the situation, devise his counter actions, while the safety systems take care of the plant automatically.

Much of the research today is concentrating on the man/machine interaction before a serious disturbance, trying to detect and counteract it as early as possible. The aims of the research are generally to avoid operational failures by man and to put him in a position to act efficiently and successfully against any disturbances.

The main activities in this field concentrated on the further development of information provided to the operators.

Recognizing that still more information on plant systems would help to keep the operator mentally in tune with the plant at any time, that on the other hand he already bears a heavy information burden now, the only way out is provide more intelligent information to him, where only few important conclusions drawn from very many pieces of information are conveyed to him.

One development which began fairly early is the STAR-system (Störungs-Analyse-Rechner). From the idea of a perturbance analysis system a general software package has been developed in the meantime, capable of dealing with several functions like post trip analysis, alarm reduction, Status surveillance, and disturbance analysis.

A system of this kind is being implemented at the Biblis B plant, parallel to the existing control room - of course - where the functioning of the system will be tested as well as its usefullness in supporting the operators.

Systems of this kind rely heavily on the correct preanalysis of events and/or plant behaviour. This analysis, including the dynamic behaviour starting from various initial conditions like full power or load follow modes of operation, can in itself be very demanding. In fact, the STAR-software package is designed to transfer the result of such analysis into an online programme, which supports one or several of the possible functions. The experience of an earlier implementation at the Grafenrheinfeld plant was that the cause-consequence diagrammatic method had to be extended to incorporate software models of the time dependent physical behaviour of some components to provide information intelligent enough to be of interest to the operators.

In the meantime a new line of development is being explored, where the latest developments in the field of informatics - artificial intelligence methods - are to be applied to the problem of information enhancement to the operator, including help not only for diagnosis of the situation but also for decision on suitable countermeasures.

Other lines of research try to extend the information available on the plant status e.g. by early fault detection or core power distribution surveillance.

Early fault detection systems installed in German plants are vibration monitoring systems of the primary circuit. They utilise the stochastic signal of displacement-, acceleration- and neutron-detectors to detect any changes in the dynamic response of the primary circuit.

The core surveillance systems apply fast computer models of the core neutron dynamics and thermohydraulics which, starting from existing instrumentation signals, provide more detailed information e.g. on the power distribution, its likely development and on the distance of parameters like fuel temperature from their safety limits, the DNB - distance to nucleate boiling being an example.

Common to these developments is the use of new display techniques as well as modern programmable microelectronics. A precondition for the introduction of these systems into the control rooms, is the proof that the systems are reliable enough to fulfil the stringent requirements of nuclear grade components. Therefore, another line of research deals with the reliability of programmable electronics, including the software and its analysis. Current projects are developing software tools to help the analysis of computer codes at the level on machine language, i.e. that form of the software which is actually run on the micro-computers. This project is run in close cooperation with the international OECD-Halden project. Current research in Germany also deals with the validation of primary signals from the process by sophisticated methods like nonlinear Kalman filters to ensure valid inputs to the information processing systems.

In addition to this more technically minded research concerning the man/machine interaction, some research is directed towards the human element.

Observation made in actual control rooms showed the teamwork in running the plant, the work load distribution for different members of the plant under various conditions, the effective way of team communications which are, because they are very short, very rarely interrupted or disturbed even under high work load.

Since in the control rooms very rarely disturbances can be witnessed the research is extended towards simulator studies, where teams of operators at a full scope simulator can be closely observed while they are dealing with preprogrammed disturbances unknown to them. The main problems of this kind of research are the huge amount of data collected even for short simulator sessions and thus the neccessity to develop efficient analysis methods and the question of sensitivity. If we not only look for normal human behaviour, but for failures and human errors, because of their low probability of occurance, very many data are required.

This research into man/machine interaction will be pursued further, continuing the very good international cooperation established so far, in particular with the OECD HALDEN-project.

Further work will concentrate on the quick and precise identification of the plant status at any moment, the improvement of knowledge on human behaviour and reliability under all operating conditions and the further development of software and electronics evaluation in safety relevant plant systems. Statistics inform that human errors during maintenance and repair work contribute to a high percentage to disturbances of plant operation. Therefore, also investigations are being initiated to analyze maintenance and repair work in order to identify the best possible conditions for its error free performance.

4.4 Risk and reliability

The main contribution to this field was the conduction of the German Risk Study (DRS). Its phase A, was initiated shortly after the release of WASH 1400, when it became obvious that the results of WASH 1400 could not easily be transferred to the German situation. So, using an approach very close to WASH 1400 but taking the German safety concept and plant technology as well as the siting and weather conditions into account, Phase A was performed.

The results obtained were roughly the same as in WASH 1400 for risk values as well as error band widths: The overall core melt freqency was calculated to 9.10^{-5} per reactor year, with an uncertainty of about an order of magnitude.

A more detailed account of the risk analysis will be discussed separately in this workshop. Here some examples shall be mentioned where the risk analysis contributed to improving plant design. One of the tasks of risk analyses is to find the relative weak points of a design, so that the overall risk can be further improved. In phase A of the risk study, while mainly confirming the validity and effectiveness of the safety design, leading contributions to the risk could be identified to be: small LOCA, because delicate operator actions were required to cool down the plant and transients, e.g. the loss of preferred power. Some system modifications have been performed e.g.

- automatic control for the cooling down procedure in the case of a small LOCA
- instrumentation of the main feedwater systems adequate to LOCA conditions
- electric power supply, modifications for return to normal power in case the emergency diesel generators fail.

With the modifications the contributions of both sequences are now well below 1.10^{-5} per reactor years.

The experience gained performing risk analyses was subsequently applied to perform a risk oriented study for the SNR 300, the German prototype of a Liquid Metal Fast Breeder Reactor. It could be shown that the risk of the SNR 300 plant is of the same order as the risk for PWRs.

In the meantime, phase B of the German risk study is nearing completion. Its aim is to reduce the uncertainties of the phase A results which were about one order of magnitude by using better data, e.g. component reliability by including operating experience, by using better analytical models or more detailed analysis methods and recent results of research work.

I'd like to mention one example that is not included in the separate talk on the risk analyses, that is question of fire hazards. This was of particular interest, since American fire hazard studies had produced very high contributions to the probability figures of core melt events. A new time dependent method has been developed whereby the effects of possible fire progression on the plant systems is treated in considerable detail. Because of the high passive fire protection due to spatial separation of redundancies in German plants, the resulting figures for core melt probability were quite low. The programme is now being continued with experimental work at HDR, where fire experiments are conducted inside the containment to provide the neccessary data for further validation of models and codes used so far.

Together with a number of international partners, we are also trying to improve the treatment of common mode failures and of operator intervention by taking part in benchmark exercises organised by the joint research establishment ISPRA.

5. International cooperation

The close international cooperation has been touched upon in several fields mentioned before. The common interest in reactor safety and the high costs of the research required, which can be reduced in cost sharing projects or exchange of research results, have always provided strong motivation for international cooperation in this field. The recent accident at Tschernobyl has underlined the international character of the reactor safety area. So we can expect that the previous exchange of views on safety issues will even be intensified, the execution of common projects and the joint evaluation of R&D results will continue.

In fact, BMFT has been engaged in a number of well balanced international exchange programmes based on bilateral agreements.

Some of our partners are

CEA (France)
EPRI and NRC (USA)
STA and MITI (Japan).

In addition, there are the bilateral contacts with the countries of Indonesia, Egypt, Brasil, Peoples Republic of China, Finland, South Korea, Portugal.
A number of larger projects with international membership have been mentioned before, like

HALDEN	(OECD)
HDR	(FRG)
LOBI	(CEC)
LOFT	(USA)
MARVIKEN	(Sweden)
PHEBUS	(France)
UPTF/SCTF	(FRG, USA, Japan), the 2D/3D project mentioned before.

In addition, the international cooperation is conducted within the large international organisations like
CEC, where the BMFT participated in the design of reactor safety research, e.g. at the research centre ISPRA,
as well as IAEA and OECD/NEA.

6. Summary and Outlook

In summary we can state that 15 years of reactor safety research have provided a considerable pool of knowledge in various disciplines. Actually, up to late 1985 the BMFT spent a total of 1,850 Mio DM for more than 700 projects.

This knowledge is being applied by all institutions concerned with reactor safety: it is incorporated in guidelines, rules and regulations, it forms the basis for safety and risk assessments and it also supported the development of the reliable safety technology of German LWR Designs.

Despite the high level achieved so far, the requirement of the best possible protection of the population and the environment against the hazards of nuclear energy calls for the continuation of safety research as one of the precautions the authorities have to take.

So, the further development of the state of the art in all fields of reactor safety, giving highest priority to prevention of accidents, will continue.

Future work will take note of industries continuous further development of plants, e.g. by adjusting currently available tools (computer codes) for safety assessment in parallel to the development of e.g. district heating or advanced pressurized water reactors.

Similarly the rapid development of programmable electronics requires the development of qualification methods which, as far as safety functions are concerned, can prove that the high standards of nuclear technology regarding absence of design faults and reliable operation are adhered to.

Also the developments in other technical fields and their possible application to reactor safety tasks will be followed up as before. As an example the potentials of artifical intelligence for helping men in diagnosis and decision making springs to mind.

A number of tasks is waiting to be addressed. For example, in the field of risk, data bank systems allowing fast information retrieval must be developed for plant, operating and reliability data. After completion of Phase B of the German risk study for PWR, an analogous analysis for BWR is due.

Although according to the knowledge presently available, the accident at Chernobyl has not shown any new phenomena or surprising new events, details of future research work may be influenced by the detailed evaluation of the Chernobyl accident, as more information becomes available. E.g. the accident may intensify research concerning the further improvement of the prevention of accidents and the mitigation of consequences.

According to the information so far at hand, the investigation of the dispersion behaviour of fission products should be addressed.

Questions with respect to fission product retention in the containment and to the source term are the next subjects of importance. Moreover, the research into fire protection and the intended further investigations of the hydrogen problem may be influenced by a detailed analysis.

In addition, planning efforts concerning accident management have been proven in their importance. This term is used to designate active measures involving the use of operational and/or simple additional systems rapidly to install in order to exercise an early influence on the sequence of serious accidents even if they have not been taken into account during the design analyses. An example illustrating such a measure would be the selected depressurization of a containment at a favorable moment in order to prevent an uncontrolled failure and a release of fission products that could no longer be coped with, which had been pointed out by the DRS B analysis.

The preconditions for the preparation of such methods include detailed information on the sequence of all kinds of severe accidents, the possibility of describing them as a prerequisite for an accident sequence prediction, and an accident-proof instrumentation to provide information on the state of the plant at any given time.

Accident management provides a considerable potential for the further reduction of the residual risk and for the limitation of the consequences of serious accidents.

2. TRANSIENT ANALYSIS AND ACCIDENT SEQUENCES

EXTERNAL HAZARDS

EMERGENCY CORE COOLING

LARGE BREAK LOCA

SMALL BREAK LOCA

TRANSIENTS

CORE MELT SEQUENCES

FIGURE 1

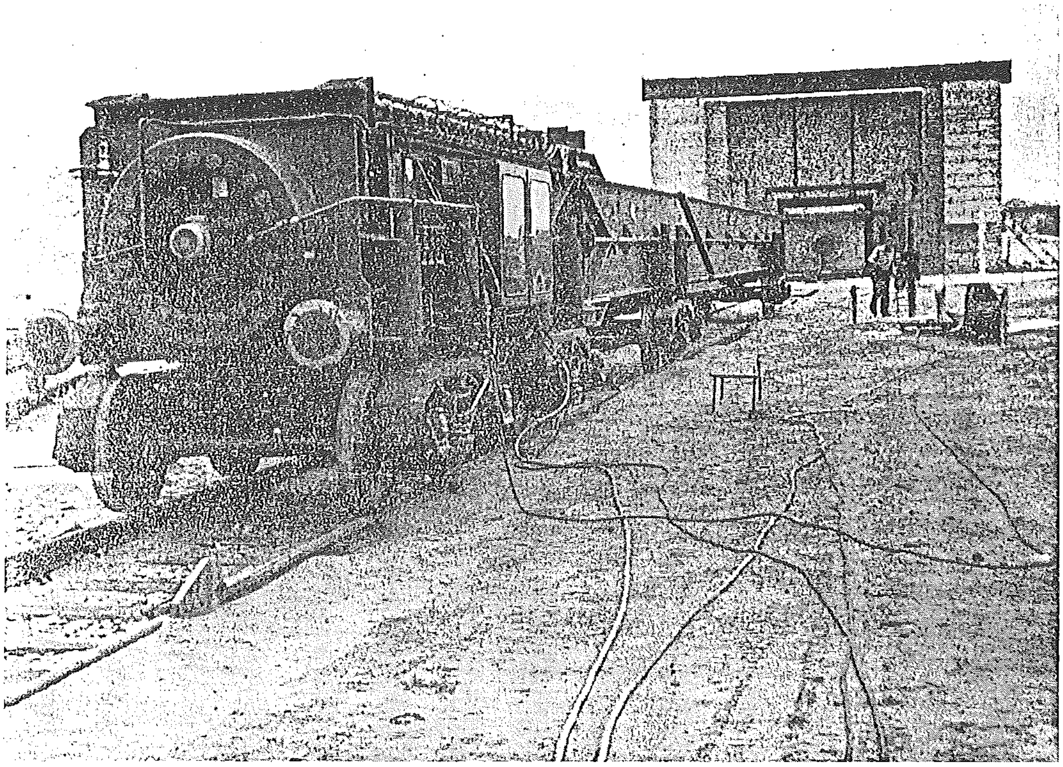
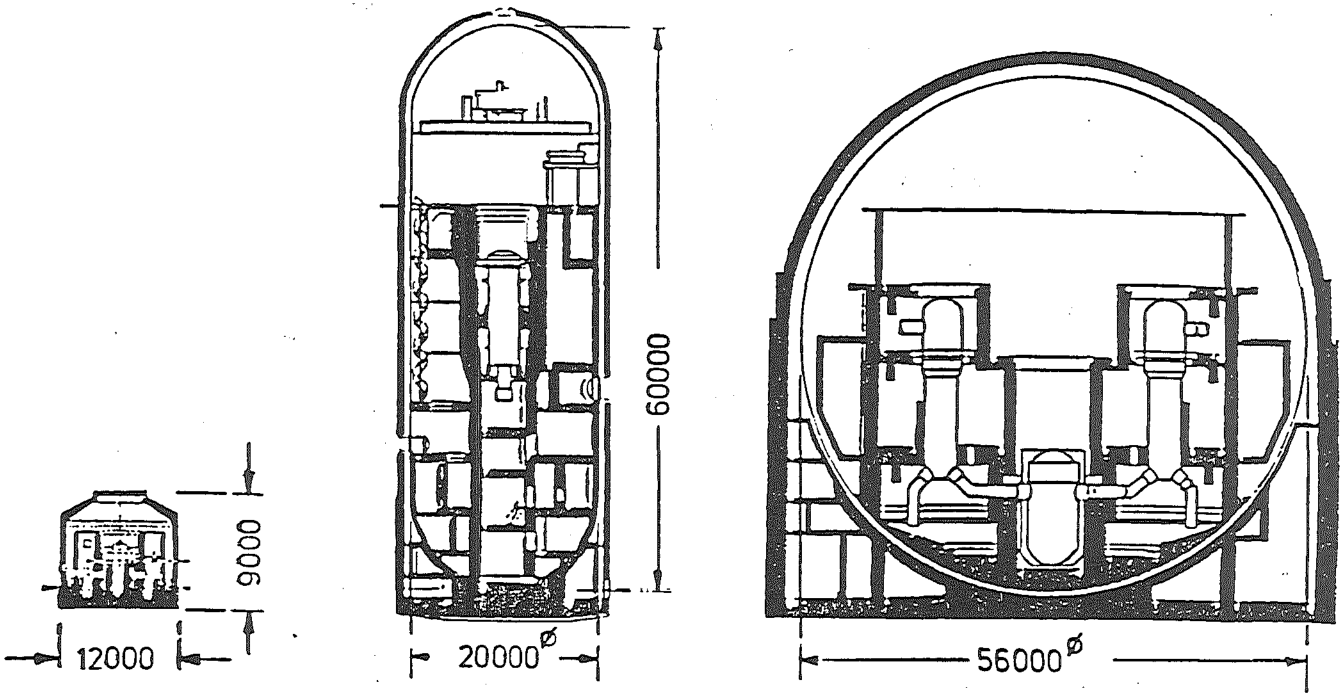


FIGURE 2



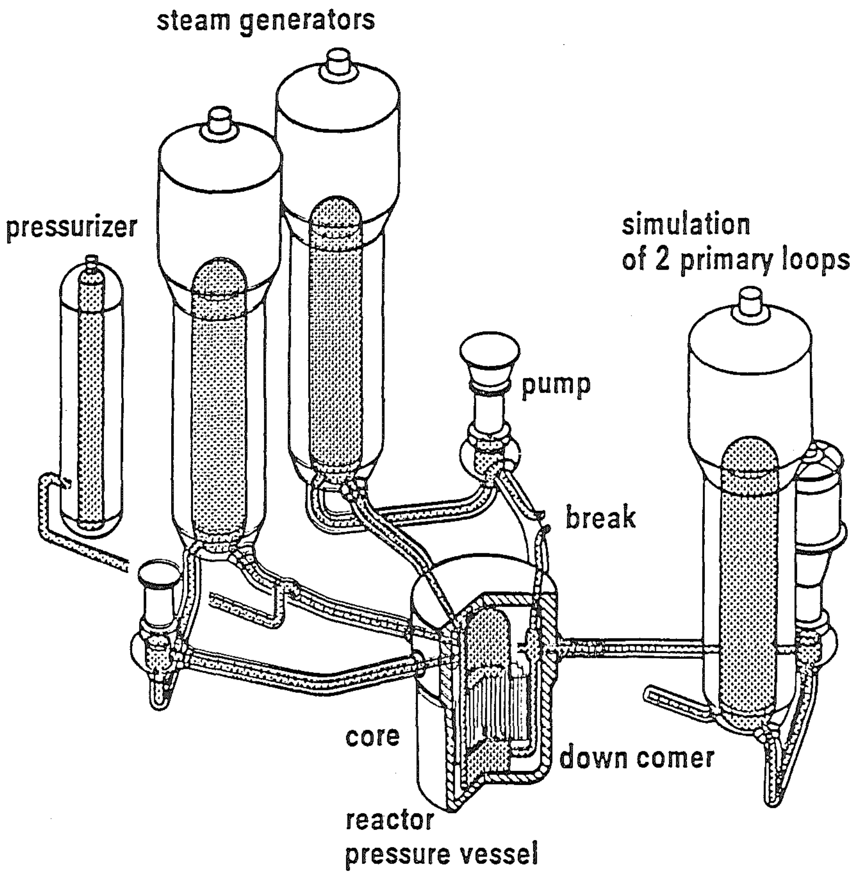
Name		Modelcont. (BF)	Hdr - Plant	DWR - Plant
No of Rooms		9	34	50-60
Volume	m^3	642	11300	70000
Concrete Surf.	m^2	1020	9400	30000
Metal Surf.	m^2	115	15600	15000

CODE - Verification

COFLOW
CONDRU

CODE - Application

Fig. 3



PKL-Systems Effects Tests:

- interplay between components
- code verification

	PWR	PKL
number of rods	45548	340
volume scale	134	1
elevation scale	1	1
primary loops	4	2+1 double
ECC-injection	8	4+2 double

PKL Simulation of 4-Loop PWR

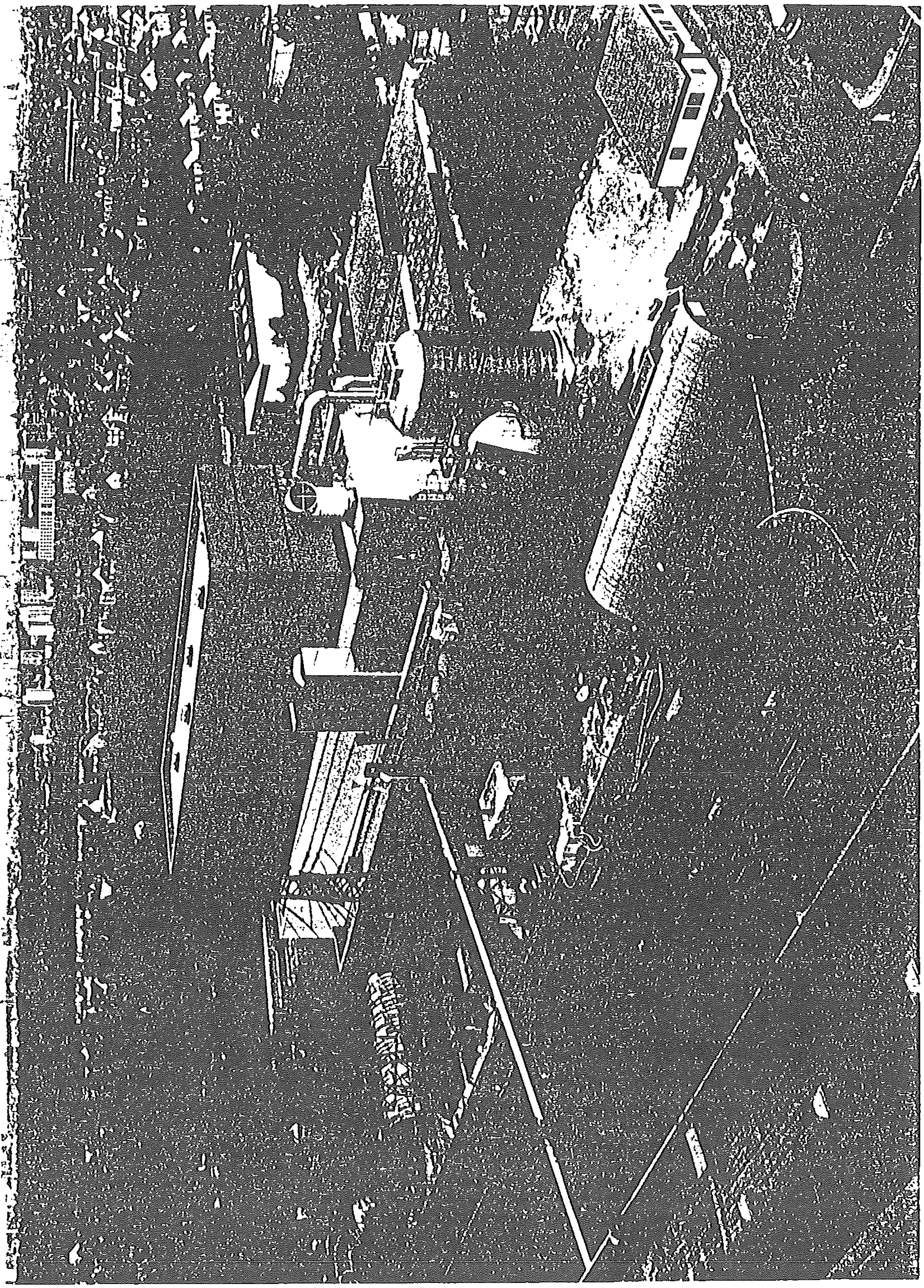
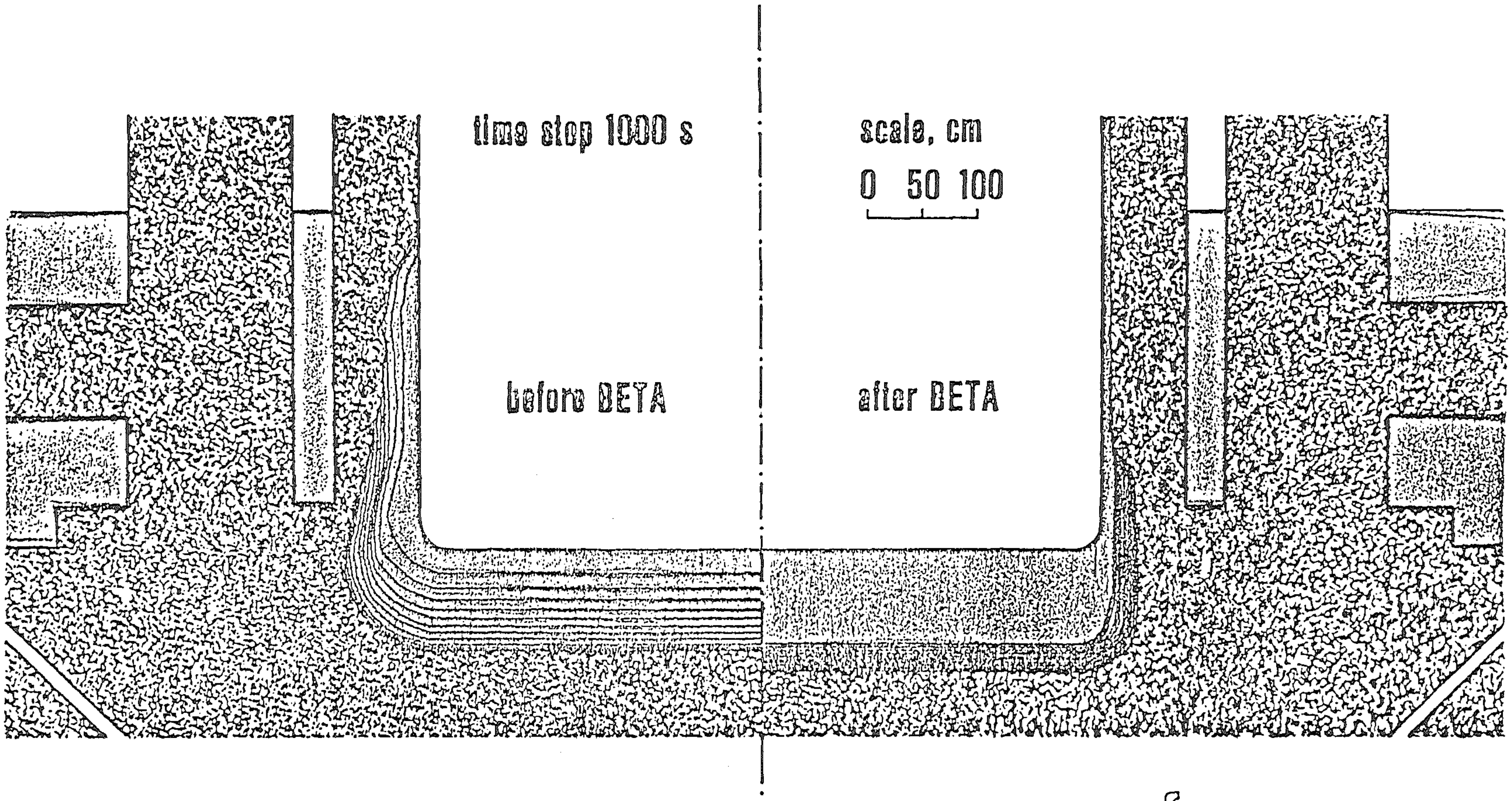


Fig. 5



Beton-Erosion after core melt down

Fig. 6

Ergonomics in Nuclear and Human Factors Engineering

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Introduction

Because technical systems are created by and for human beings, it is important for the dimensioning to take human concerns into account. Determining the mode of operation of a technical system also entails making decisions on the future tasks of its users and operators. For complex technical systems, like power plants or chemical industrial installations it is essential to include the consideration of human characteristics and capabilities at an early point in the development process. This is related to safety of operation as well as to reliability and availability and thereby governing economics.

At this interface between man and machine ergonomics and human factors engineering are required.

A definition of ergonomics is given in Fig. 1. Ergonomics refer essentially to the data and principles concerning human characteristics and abilities as obtained in the fields of anthropometry, physiology and psychology as well as the application of this knowledge to the dimensioning of workplaces, machines, equipment, work cycles, and environments. Some important ergonomic parameters are listed in Fig. 2. Within this overview only a compact summary can be given. More details are shown in /1, 2, 3, 4/.

Beside this data set there exists another very important aspect of man-machine-interaction as shown in Fig. 3. Time constants of

- processes running in technical plants,
- information transport and processing either for man or automatic control systems and
- initiation of actions

have to be carefully evaluated and adjusted to get finally a stable process control and not an oscillating diverging control loop running out of all limits. Fig. 3 shows already the principle of a combined system control using human capacity as well as automatic control paths, the latter for response time shorter or too large for human beings.

Technical equipment should be designed so that after learning the individual functions the operator can run it reliably. This calls for action based on rules. Failure to observe instructions and operating procedures can have negative effect on the operation of the equipment, sharply reducing its availability and safety.

Existing systems, planning methods already in use, and a growing number of advanced training options for ergonomic concerns lead to cooperation of engineers and ergonomists in the preparation of ergonomic standards. One example in Fig. 4 shows the DIN-standards to be included in the design of a video display unit (VDU) workstation. One may easily recognize several areas out of the data set of Fig. 2.

As this paper shall concentrate on nuclear power plant aspects the work situation there including man-machine-relationship is described in the next chapter.

2. On Power Plant Working

Looking for work situations in power plants one has to include different areas, e.g.

- the main control room
- local control boards inside the plant or at auxiliary systems
- electronic and computer rooms
  (a part of the action zone in Fig. 2)
- power switch rooms
- offices
- workshops
- at subsystems and
- on transport facilities like cranes or vehicles.

By the differences of those locations it is obvious that we need careful considerations on the anthropometric design of the respective work places. Additionally these work places may be used continously or only for a short but determined time.

The tasks to be performed need also special consideration. Important examples for power plants are

- surveillance of totally or partialy automated processes
  (a more visual work)
- control of non automated processes
  (as a more mannual example)
- maintenance and repair in workshops or in the plant itself and last not least
- documentation and preparation of records in offices or on site.

For these different tasks the adequate tools are to be designed and organized in a user oriented way e.g. on control desks or in workshops.

User oriented - here we are! Man comes into the business! Tools, work-pieces, machines, plants are designed by man for special use and according to standards, regulations, design criteria - but what about man? If we look for man to step into responsibility in man-machine-interaction work, we always ask for e.g.

- ability, skillness, qualification
- training and knowledge.

For planning purposes we have to keep in mind that characteristics of human beings can be subdivided into three groups

- unchangeable:	sex anatomy genetic base race social background
- changing:	age mass of body health conditions physiological efficiency psychological stability
- changeable:	abilitiy skillness experience knowhow.

This situation leads to selections under different patterns of requirements for electricians, car-divers, pilots, power plant operator etc., followed by different training procedures for preparation for the real job - then under the load of responsibility.

Training and preparation is one very important part of man-machine-interaction not only in critical situations as explained below for the Harrisburg and Chernobyl accidents but also for keeping the required quality standard over the life period spent on the respective job - as a safety relevant object and part of the integral system.

In power plant control rooms in the case of constant load events which need special attendance are rare. This situation is as bad for human observation as events constantly occuring over a longer time period. There automatic systems with a discriminating capacity are much more reliable. Such systems on the other hand, need clearly determined signals with low noise. For a trained man the interpretation may still be possible if the level is low or parts are missing although a behaviour in steady expectance may lead to make him seeing what he wants to.

For information retrieval and processing a similar differentiation between human and machine capacibilities can be done, also for control. This evaluation allows a systemoriented method of development with clearly devided tasks according to abilities and optimized for the process under consideration. One of the important criteria for this optimization is to get a situation with the highest degree of reliability and safety of operation.

As an example of ergonomically structured control room we may have a look on the MPR 30 design. An artist's view is given in Fig. 6 which shows together with the plan in Fig. 5 the arrangement of control boards and desks. From the reactor control desk the visibility of the important main circuits is guaranteed by being directly in front. Reactor protection and radiation protection are more oriented towards the communication desk.

The use of analog instrumentation, indication lights or illuminated panel alarm indicators as well as video display need a carefully planned lighting system to give a clear impression of the different states of the indicators without any doubt to the responsible operators.

3. Lessons Learned From Accidents

It is a striking and astonishing situation that nearly all accidents in nuclear power plants which have occurred until today, have been caused or at least aggravated in their accident sequence by human error and actions of the personnel. With this regard automation of process equipment, instrumentation and controls, the education of operators for normal operation and especially for accidents and under stress is an absolutely neccessary prerequisite for a save operation of nuclear power plants.

Beside the theoretical analysis of man-machine-problems particularly in the field of nuclear energy production there is a possibility to learn special lessons about this topic analyzing the two accidents which are without any doubt the biggest accidents in nuclear history: The nuclear accident in Three Mile Island, Harrisburg, USA on March, 28, 1979 and the nuclear accident at Chernobyl, USSR, on April 26, 1986. Whereas the first of these accidents has been analysed to a very far extend leading to recommendations for other nuclear plants in the USA and with lessons learned for all nuclear operators in the world, the second is just in the phase of international discussion. In the TMI-plant a lot of technical faults and especially human errors led to an accident that came to a partial core melt down and to the fear that a big amount of radioactive fission products could be spread to the environment. This could be prohibited by the tight containment, which covers the whole nuclear installation and retained the nuclear material inside the plant without demaging the environment. Therefore the radioactive burden outside the reactor was only extremely small.

A commission which was chaired by John Kemeny analysed the accident and stated, that without human errors, the accident would have been by far less significant. The specific problem was, after the commission's report, the failure to recognize the actual conditions of the plant. But the commission related this fact to much broader problems of competence, background and training of both operators and management. The commission pointed out that although operator examinations where consistent with regulations, they did not ensure, that candidats for a operator license had an in-depth knowlegde of nuclear reactor theory, design and operation. The report explained that training for operators concentrated on systems, equipment and procedures rather than on basic scientific and technological concepts, such as thermodynamics, decay heat production, or system operation. So it was recommended that operator qualifications, training and licensing had to be improved. In this area consideration should be given more to educational background, to training methods, and to the content of the training programme. Attention should also be given to testing methods with specific concern for the ability of the testing method to predict operator capability. Requalification, training and testing should be similarly examined to ensure that the operators take account of information that is developed by operation in the plant and to ensure that relevant information about other plants is made evalable to operators and is made part of the training and requalification programme. The use and limitations of simulators for operator training should receive carefull consideration.

With respect to these findings it seems to be of high value and worth mentioning that in German power plants the operator is not forced to take any action within the first thirty minutes after an accident initiation. Up to a very high extend the recommendations of the Kemeny-Commission have already been realized in the Federal Republic of Germany as far as operator training, simulator-training and personnel education is concerned. Automatic is given an even higher rank than it is given in the United States. Nevertheless in consequence of the TMI accident the German licensing authorities have recommended better instrumentation, better technical procedures for the operator and simplifications for processes which are executed by the operator, further development of programmes for simulator training, better information for the operator about the status of the systems and for the development of the automatic plant protection system.

The Chernobyl accident was caused by an experiment evaluating the capability of the residual energy of the rotating turbine for the emergency power supply of the pumps. Partly according to the test programme and partly without regard to it a number of safety conditions where blocked, which were relevant for the reactor emergency shut down and the emergency core cooling system. A special feature of the reactor, a positive void coefficient of reactivety, led to a sudden extreme power excursion and in consequence to a total destruction of the reactor. Due to the fact that the reactor did not have a tight containment at all a massive release of radioactive fission products occurred to the environment. This did not only expose the neighbours of the plant but also, to a much less extend, the inhabitants of eastern and central Europe.

The report of the USSR State Committee on the Utilization of Atomic Energy about the accident at the Chernobyl Nuclear Power Plant /5/, which was presented to the IAEA in August of this year, identified a number of man-machine- problems, which have led to the accident. First the twenty years old construction concept allowed interventions to the protection system even in the direction going to less safety. Second there was a lack of safety systems and automation which ensures the safety of the reactor even in the case of human error. Finally the test programme did not correspond to the safety rules, and this test programme was not even followed.

Appenrently the personnel was not suffiently informed about the peculiarities of the plant and about the processes which where to be expected in consequence of the experiment. There is only one simulator for the RBMK-type reactors located at Smolensk, which is apparently not suffient for the operating personnel of more than thirteen reactors of this type in the USSR.

The chief motive of the staff was to complete the experiment. The failure to adhere to instructions in preparing for and carrying out the experiment, the non-compliance with the testing programme itself and the carelessness in handling the reactor facility are evidence that the staff was insuffently familiar with the special features of the technological processes in the nuclear reactor and evidence also that the operators had lost any feeling for the hazards involved.

The designers of the reactor facility did not provide for protective safety systems capable of preventing an accident in the combination of circumstances prevailing in the reactor. These were especially combined with the positive reactivity coefficients and the deliberate switching off of technical protection systems couppled with violations in the operating regualations.

So, the working groups of the above mentioned IAEA conference recommended for a future international cooperation among other points international exchange of experience about the man-machine interface, an international conference about the balance of automation and human action in the operation of nuclear power plants and finally an international exchange of experience about the efficiency of training and education methods for reactor personnel.

It is to be expected that those experiences taken from the reactor accidents in Harrisburg and Chernobyl will play there role in improving ergonomics in nuclear safety and in human factors engineering.

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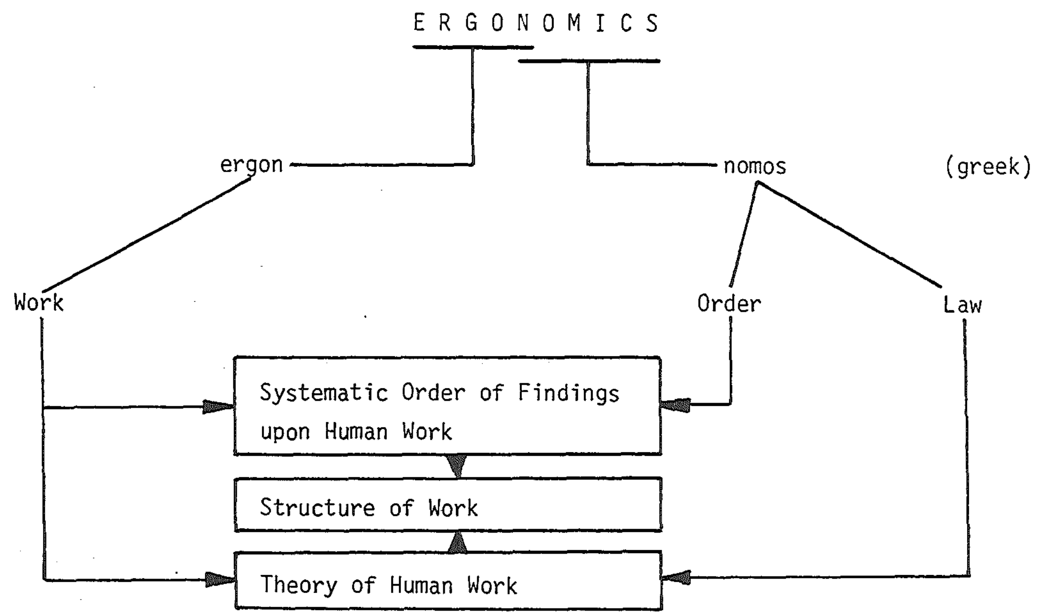
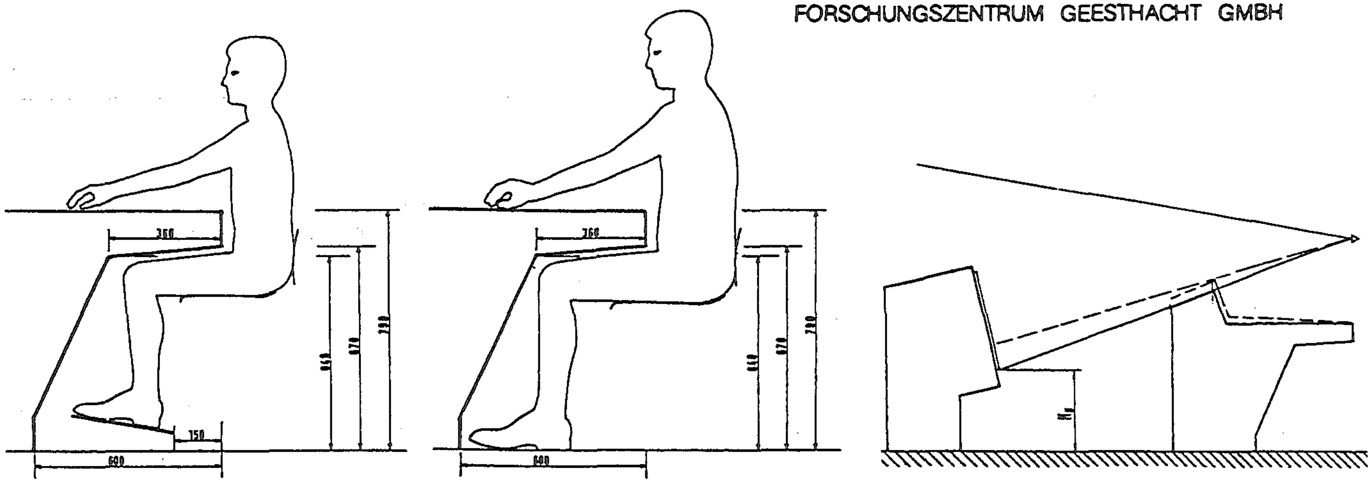


Fig. 1: Definition of Ergonomics



Human Body Dimensions and Strong Dependance on Visual Information

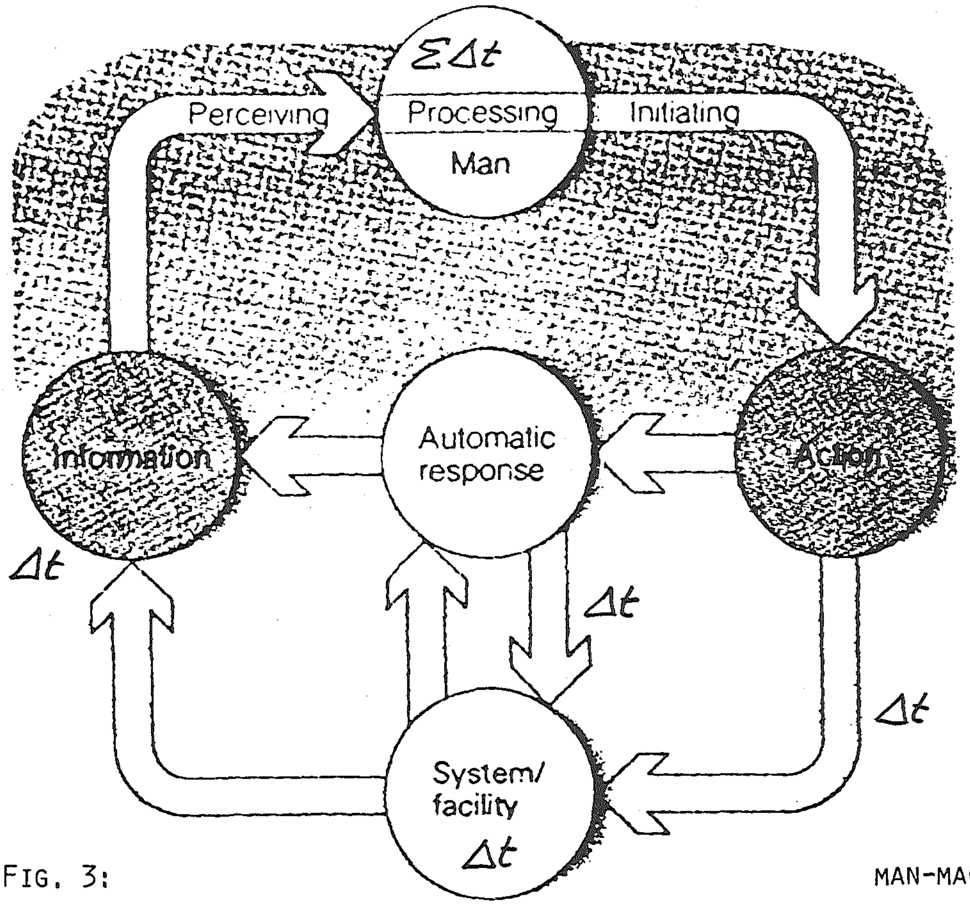
Human Load: - Physical
- Psychological
- Periodic
- Stochastic

Human Characteristics

Human Knowledge

Physical Influences: - Light
- Mechanical Vibration
- Sound
- Climate: - Temperature
  - Humidity
  - Air motion
  - Heat Radiation

Fig. 2: Important Ergonomic Data



Δt = TIME CONSTANT

FIG. 3: MAN-MACHINE-INTERACTION /1/

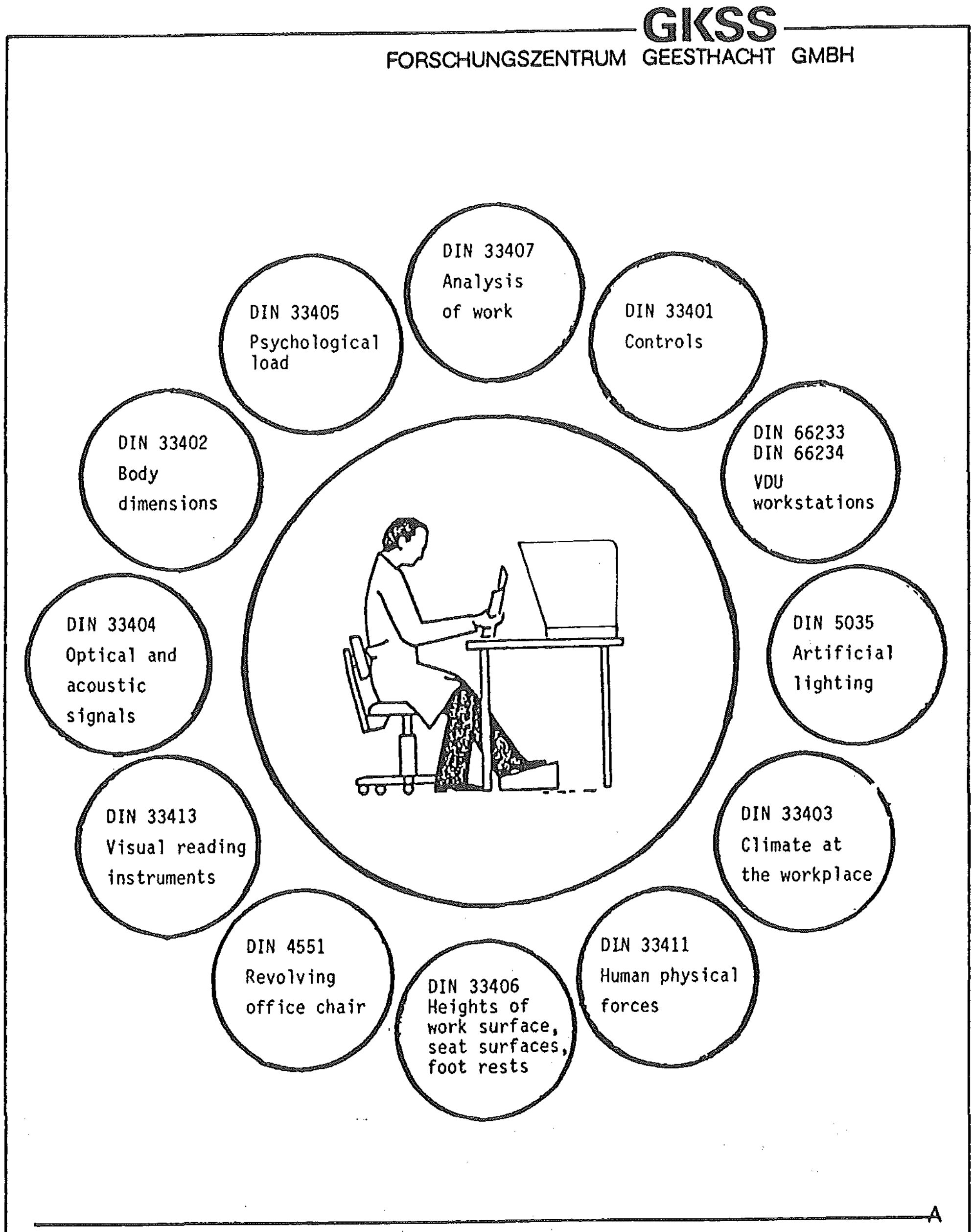
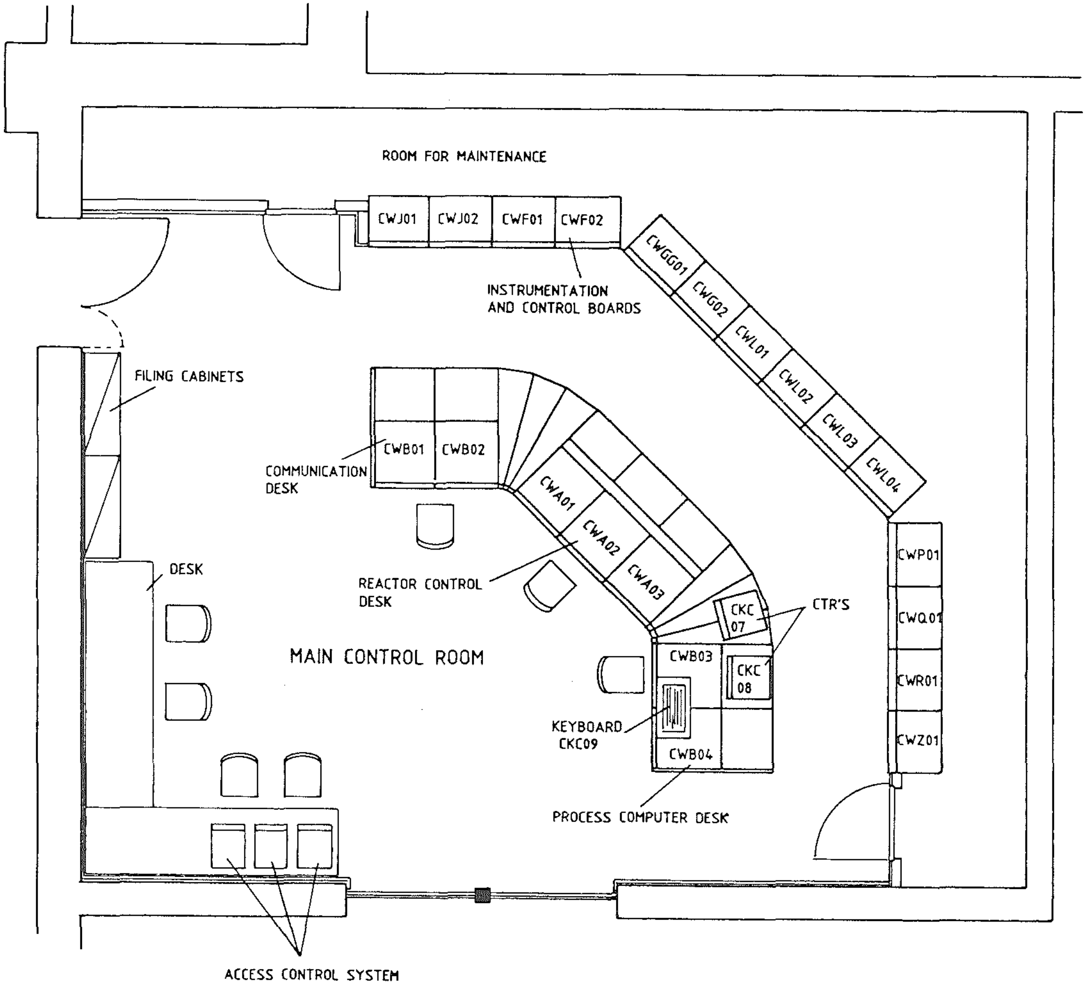


Fig. 4: Ergonomic related German Industrial Standards (DIN) for the design of VDU workstations /1/



CWJ01, CWJ02 – REACTOR PROTECTION
CWF01, CWF02 – RADIATION PROTECTION
CWG01, CWG02 – VENTILATION
CWL01, CWL02, CWL03, CWL04 – MAIN CIRCUITS
CWP01 AUXILIARY SYSTEMS
CWQ01 ENERGY
CWR01 FIRE
CWZ01 EXPERIMENTS
CWA01, CWA02, CWA03, CWB01, CWB02, CWB03, CWB04 – CONTROL DESK

MPR 30 MAIN CONTROL ROOM

FIG. 5

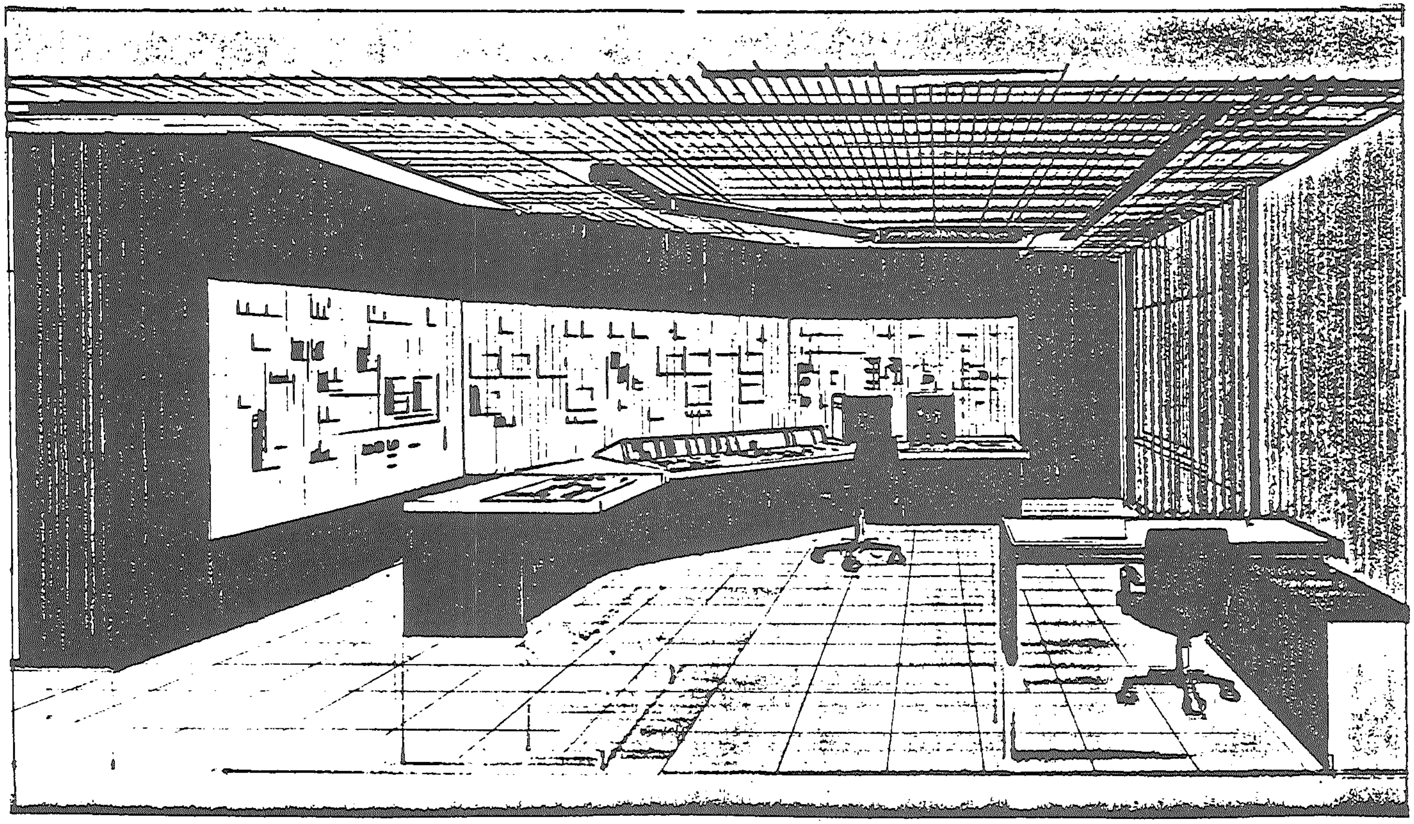


Fig. 6: MPR 30 Main Control Room

ROLE OF STANDARDS AND CODES IN ENHANCING NUCLEAR SAFETY

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Introduction

At the inception of nuclear energy, standards and codes specific to nuclear safety were virtually non-existent. Today, a licensing procedure without them is almost inconceivable. There is no doubt that safety standards and codes have become to play an increasingly important role in the licensing of nuclear facilities and that they contribute largely towards optimizing the overall safety. But what are standards and codes? It would perhaps be useful to dwell on this question for a while before passing on to some of the other interesting aspects.

What are Standards and Codes?

The NUSS program (Nuclear Safety Standards) of the Internatinal Atomic Energy Agency (IAEA) talks of Codes of Practice and Safety Guides, the USNRC talks of Regulatory Guides and in the Federal Republic of Germany it is the Nuclear Safety Standards. But, irrespective of the names, they can all be broadly defined as requirements which must be fulfilled to ensure nuclear safety. Each set of standards, again, is made of various types of standards which are either reactor specific or are independent of reactor type, which spell out either basic or general requirements or detailed and perhaps component specific requirements. In all cases, however, there is a more or less clear demarcation between legal and technical aspects. At the same time, there is a definite relationship between the legal regulations, which define the protective aims and the standards, which set out the requirements for the technical means to achieve these protective aims. The situation in Federal Republic of Germany can be looked at, as an example, to consider the hierarchy of the regulations and standards (see Figure 1).

A comparison with the situation in the United States and France shows a similar set up (see Figure 2).

So, at the national level, an Atomic Energy Act or Federal Regulation and Ordinances define the protective aims to be fulfilled, and this represents the peak of the pyramid. At the base, the safety standards specify the safety related requirements i.e. specific to nuclear facilities, for the technical means to achieve those aims; conventional standards specify the non-nuclear requirements, and industrial norms are applied to non safety related items.

When the international scene is considered, there is no atomic energy act or similar legislation which is applicable to all countries. But there are recommendations and safety standards developed by international organisations like IAEA, ISO and IEEE. The NUSS standards of the IAEA are the first comprehensive set of nuclear safety standards at the international level. The NUSS standards, however, have the disadvantage of being basic and general in nature, since they have to cater to the needs of all member states of the IAEA and have to be approved by all the member states before being published in their final version. But, they deal with the areas of governmental organisation and personnel training which, at the national level, are within the responsibility of the government (the Federal Republic of Germany is taken as an example here) and are thus not included in the safety standards.

The Federal Republic of Germany can be taken as an example to see what is available in terms of safety standards relevant to the nuclear licensing procedure. If the pyramid is considered once again, directly below the level of the Atomic Energy Act /1/ and the ordinances are the Safety Criteria /2/. This document, although technical in nature, has been issued by the government and is considered to have a higher rank in the hierarchy than a standard. Drawing up the Safety Criteria was a first step towards rendering the legally worded safety requirements of the Atomic Energy Act and the associated ordinances more concrete by technical provisions. The safety criteria have, in particular, been developed for nuclear power plants with light water reactors. But, a set of similar criteria for gas-cooled reactors is presently being developed.

Below the level of the safety criteria are the safety standards. This category includes primarily the KTA safety standards and the regulatory guides issued by the Federal government. The KTA (Kerntechnischer Ausschuß = Nuclear Safety Standards Commission) is a 50 member commission instituted by the Federal Government and consits of representatives of all groups involved in the nuclear licensing procedure, including industry. The set up and procedures of the KTA are discussed later in the paper. The KTA safety standards detail requirements for all phases of the construction and operation of nuclear power plants with respect to quality assurance, design, manufacture, operation and surveillance. A complete list of the program of the KTA safety standards can be seen from Table 1.

Regulatory guides are in part specifications by the authorities regarding the licensing procedure and therefore not classified as safety standards. However, the government also issues regulatory guides, which are technical in character. This is done in cases where KTA safety standards are not yet available. These technical guides are replaced, in time, by the corresponding KTA safety standards, when these have been completed.

A special role within the level of safety standards is played by the RSK-Guidelines /3/. The RSK (Reaktor-Sicherheitskommission = Reactor Safety Commission) is a commission which advises the Federal Government on issues related to nuclear safety. The guidelines are a condensed summary of the safety requirements which, according to the commission, should be met for the design, construction and operation of nuclear power plants. The purpose of the guidelines is primarily to simplify the deliberation process within the RSK and to give an indication, within a relatively short time and early in the licensing procedure, as to the requirements considered necessary by the commission. Such guidelines exist, as of the present time, for pressurized water reactors and boiling water reactors.

The RSK-Guidelines can be considered as an interim measure between the safety criteria and the KTA safety standards. For areas where KTA standards are completed, the RSK-Guidelines replace the text of the guidelines by a reference to the relevant KTA safety standard, with supplementary comments or requirements, should they be considered necessary.

Below the safety standards on the pyramid are the industrial norms.One of the most important organisations working on industrial norms is the DIN (Deutsches Institut für Normung = German Standards Institute). The DIN establishes norms in all areas of technology. The KTA safety standards make reference to DIN norms where details are considered necessary.

Why is it necessary to establish Standards and Codes?

The obvious answer to this question would be: in order to achieve a uniform level of safety. Since the advent of Chernobyl, one should say: in order to achieve a uniformly high level of safety on an international level. But, this answer should be analysed in the context of national practices. The Federal Republic of Germany can again be taken as an example. The nuclear licensing and supervisory procedure in the Federal Republic of Germany is strongly influenced by the federal structure of the country /4/. In accordance with the principle of as much centralism as necessary and as much federalism as possible, the responsibilities in the area of the peaceful use of nuclear energy have been defined such that nuclear legislation is enacted at the federal level but the individual states are responsible for the implementation of these laws. The individual states are the licensing authorities and it is to them that an application for a license to build and operate a nuclear facility is made. There is, of course, a great deal of interaction between the federal and state ministries, the experts and the various advisory groups before a license is issued (see Figure 3). But, each state is autonomous and is responsible for the licensing of a nuclear facility within its boundaries. It is therefore of the utmost importance that a nuclear facility in one state is as safe as one in any other state and that experiences gained with the construction and operation of one facility be passed on for the licensing of others. It was in this context that the Safety Criteria were drawn up, the RSK established and the KTA instituted. These have contributed a great deal towards optimizing plant safety and thus standardizing it at a high level. Especially with the KTA safety standards, the nuclear licensing and supervisory authorities now have an instrument with which they can assess all plants in the Federal Republic of Germany on an equal basis and thus provide a high level of safety in accordance with the current state of science and technology.

In the United States of America, there is one central licensing or regulatory authority, the US Nuclear Regulatory Commission, which has been empowered with the issue and revoking of licenses. But, there is a multitude of architects/engineers, all with their own designs, and utilities with their own individual wishes as to how the plant they need should be designed. Then there is the additional problem of siting a plant in a vast country like the US with its high seismicity, especially on the west coast, and the various natural events like tornadoes and tsunamis. Considering all these factors, it was esential that some kind of standard requirements be made in order to achieve a uniform level of safety. Out of this necessity the NRC Regulatory Guides were born. These Regulatory Guides were probably the first nuclear safety standards ever made.

In France, there is a central body for regulation and for promotion of nuclear facilities. With the large number of nuclear power plants being built, is was essential to standardize requirements and thus achieve optimum safety. Standardization of plants is also an important factor when the question of export of nuclear power plants is considered.

So far, the necessity of safety standards has only been considered from the point of view of safety. But, there is perhaps a legal aspect also to be considered. In the case of nuclear facilities, there are a great deal of discussions and words like risk, possible damages, responsibility, liability, litigation, compensation, are often heard. Till the advent of Sellafield, three Mile Island and especially Chernobyl, there were all quite theoretical discussions. But, the judiciary has always found it difficult to assess the safety of a technology and especially a complicated technology like the nuclear technology. So, safety standards have been welcomed by them in their efforts to come to an impartial judgement regarding the dangers arising from one plant or the other. The nuclear safety standards like the KTA safety standards reflect the precautions to be taken in accordance with the state of science and technology at a given point of time and in the case of a litigation, these can be taken by the judiciary as a yardstick of how much safety is possible and necessary.

Differences in National Practices

One of the first steps in the preparation of the NUSS standards of the IAEA was the so-called collation. This was essentially an analysis of the materials sent in by the member states and a comparison as to the differences and similarities. It was quite obvious from the beginning, that, especially in certain areas, the differences would be quite considerable. One of the problems in establishing NUSS standards was to come to a compromise with regard to these differences and at the same time write in as much details as necessary into the codes of practice and the safety guides.

In this connection, reference should be made to a paper on an international comparison between norms and safety standards /5/. This paper essentially compares certain requirements in the NUSS program with those in USA, France and the Federal Republic of Germany.

At this juncture, two features which are probably unique to the licensing procedure in Federal Republic of Germany should be mentioned. These have been incorporated into the KTA safety standards and have contributed largely to the safety of nuclear facilities. The first is the participation of authorized experts in the licensing procedure. In the Federal Republic of Germany, these experts are generally employees of the GRS (Gesellschaft für Reaktorsicherheit = Reactor Safety Company) or of the TÜV (Technischer Überwachungsverein = Technical Supervisory Organisation) in each state. The experts of these organisations are called in by the authorities (authorized experts) to carry out assessments and tests to ensure the safety of the nuclear facilities. Both the initial tests and the in-service inspections in the facilities are carried out by the utilities together with, or in agreement with, these authorized experts. The issue of licenses by the authorities based on the reports and expert assessments of these authorized experts.

The second area is quality assurance. One can generally state that the testing for quality assurance in the Federal Republic of Germany is object oriented rather than system oriented as in USA. These tests, which are carried out by the architect/engineers and utilities together with the authorized experts, requires a very high effort in terms of man-power and costs. But, they contribute a great deal to safety.

Who establishes such Standards and Codes?

In the case of the NUSS standards, no explanations are necessary. In the United States, the Regulatory Guides are primarily written by the staff members of the US Nuclear Regulatory Commission. In the Federal Republic of Germany, the KTA safety standards are established by the KTA. The details of the procedures used in establishing KTA standards, are discussed in the two papers /6/, /7/.

In all the cases mentioned, one of the essential pre-requisites is the experience gained, especially in the licensing procedure, and this is a major input into the establishment of the safety standards. The mandate of the KTA, e.g., according to the document instituting it, is to develop and promote the use of standards in the area of nuclear technology where, on the ba sis of experience, a consensus is expected from manufacturing, utility, regulatory authority and safety reviewing organization experts.

The Atomic Energy Act was enacted in 1959. But, only in 1972 was the KTA instituted and the work on KTA safety standards begun. The interim period and the period since has gone towards gathering this important component namely experience.

The NUSS program of the IAEA was launched in 1974. The first step for the preparation of each code of practice and safety guide, as mentioned earlier, was a collation of material obtained from member states. This means that the experience gained by the member states in the licensing, construction and operation of nuclear facilities was the major input into the NUSS standards.

Without this experience, which has been gathered over several years, it is virtually impossible to establish meaningful safety standards. There are practically no "short-cuts" to achieving and optimizing safety. So, a country with a relatively new nuclear program or a country embarking on a nuclear program must be very careful in deciding on the safety requirements to be applied to its nuclear program. The NUSS standards have been envisaged for this purpose, but they are only basic requirements and thus have to be supplemented by further detailed requirements. It would, of course, be possible to think in terms of using the national practices of one or more countries with the necessary experience. This automatically leads to the topic of transferability of existing safety standards.

Transferability of Safety Standards

A country embarking on a nuclear program is immediately faced with the problem of the requirements to be applied to, and consequently the standards to be used for, the program. It is probably neither useful nor possible for this country to establish its own complete set of standards. If a nuclear power plant is being bought from another country with an established nuclear program, it is probably far more advantageous to apply the standards of that country to the plant. But, the standards would have to be adapted to consider the characteristics specific to the country and the site, e.g., seismicity, geology, population distribution around the proposed site. This is the practice, e.g., in Switzerland. The NUSS standards are also used, but they have the disadvantage of not having enough details. The Swiss licensing authorities normally accept United States standards for a plant bought from the United States or German standards for a plant from the Federal Republic of Germany. These standards, however, are scrutinized carefully to ensure that they meet all the requirements considered necessary in Switzerland. This can be complicated though if, e.g., the nuclear steam supply system is from one country and the balance of plant from another.

The NUSS standards have been established with the intention of helping countries embarking on a nuclear program. But, as mentioned earlier, these codes and guides contain only the basic requirements. These could be supplemented by the detailed requirements of a country with an established set of standards, e.g., USA or the Federal Republic of Germany, for those areas where details are considered necessary. However, extreme caution needs to be exercised if only certain elements of a national practice are adapted. Then, the safety of a program is ensured through its entirety and the program is made up of the individual requirements. Examples of the practice in the Federal Republic of Germany can be taken to illustrate this point: there are no requirements any further with respect to pipe whip restraints in the containment vessel. If one takes this as an isolated statement one could come to the conclusion that the safety is probably being reduced. But this is not true. Through a series of quality measures, the pipe whip restraints have been made unnecessary. These measures are essentially the "Basisssicherheit" or basic safety of systems of nuclear power plants in the Federal Republic of Germany. Some characteristics of this should be briefly outlined, since this is probably specific to the Federal Republic of Germany. Very stringent requirements are made with respect to the choice and manufacture of materials. This consists of

- review, prior to maufacture, of the manufacturing documents (specified valves)
- assessment of the manufacturer by the authorized expert
- tests and inspections during the manufacturing process (accompanying tests and inspections) independently by the authorized expert and by the manufacturer
- assessment by the authorized expert subsequent to manufacturing to verify whether the specified values correspond to the actual values
- documentation.

The material used for the reactor coolant pressure boundary must meet requirements with respect to high fracture toughness, low tendency to brittle fracture and high tensile strength.

As a result of these measures, the double ended pipe break has been excluded as a design criterion except for the design of the containment vessel and the emergency core cooling. For the pipes, a 10% break criterion applies, i.e, 10% of a pipe cross-section as the rupture area. This, however, is a conservative estimate of a hypothetical crack. The values are actually much smaller. But, the important fact is that the "leak before break" criterion applies and this is ensured through the measures outlined.

Other examples of cases where caution is necessary in transferring elements of a national program could be the question of redundancies of equipment of the safety system and of the emergency power supply.

In principle, though, it is possible to take a basic program like the NUSS program and to supplement it with the detailed requirements of a national practice provided that those requirements are adapted to the specific characteristics and needs of the country concerned and the overall safety through the program is ensured i.e., there is no reduction in safety through omitting key elements of the national practice considered.

Conclusion

Nuclear safety standards and codes have more than proved their worth over the last decade and have firmly established themselves as an important element in the nuclear licensing procedure. In the Federal Republic of Germany, there is a direct relationship between the safety goals defined in the legal documents (Atomic Energy Act and Ordinances) and the experience gained as reflected in the requirements of the safety standards. This has been instrumental in achieving the high level of safety and maintaining it at that high level. But, the optimization of safety is a practically neverending process, especially in the area of nuclear technology. Standards and codes cannot afford to be stationary. It is essential that advances in science and technology and the invaluable experience gained from the construction, operation and decommissioning of nuclear facilities be an input into verifying whether existing standards need to be modified or updated. This was one of the important topics of dicussion at a recent IAEA symposium on NUSS standards. The KTA standards program has a built-in feature to review standards periodically in this context.

In the aftermath of Chernobyl, it is hoped that an international exchange of information and experience can be realized to optimize safety at the global level. Existing safety standards and codes can contribute a great deal towards this effort.

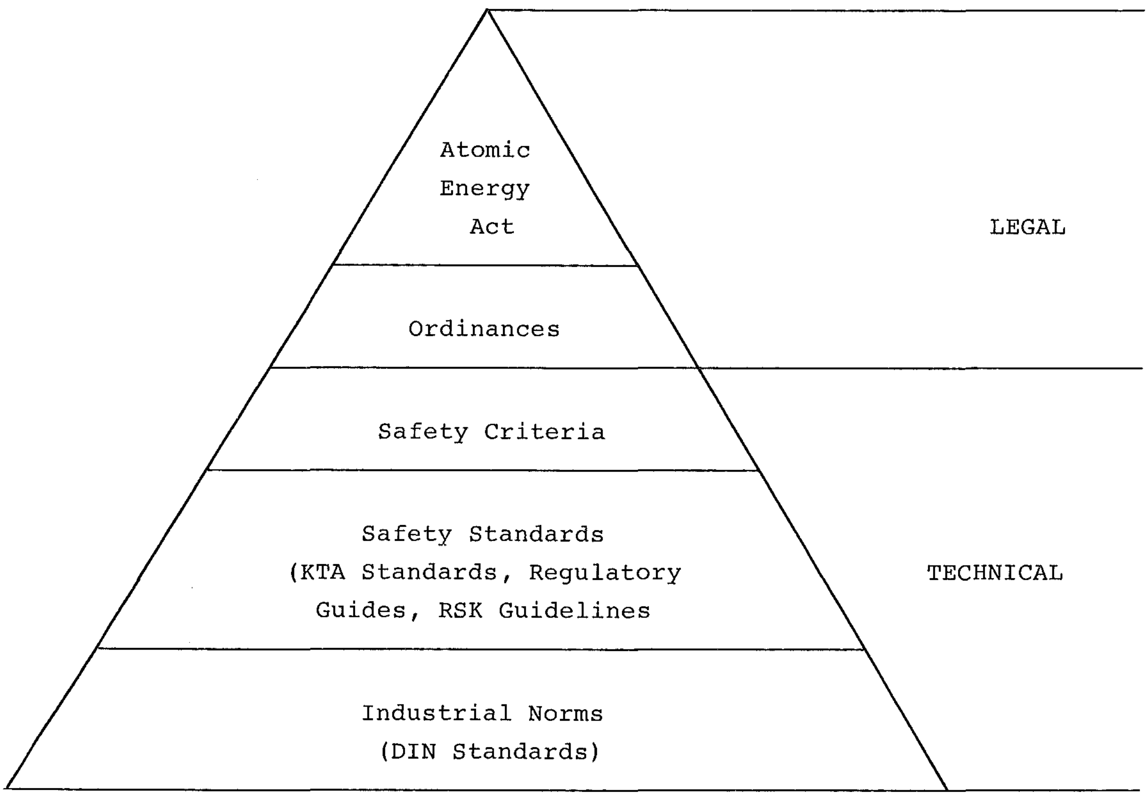
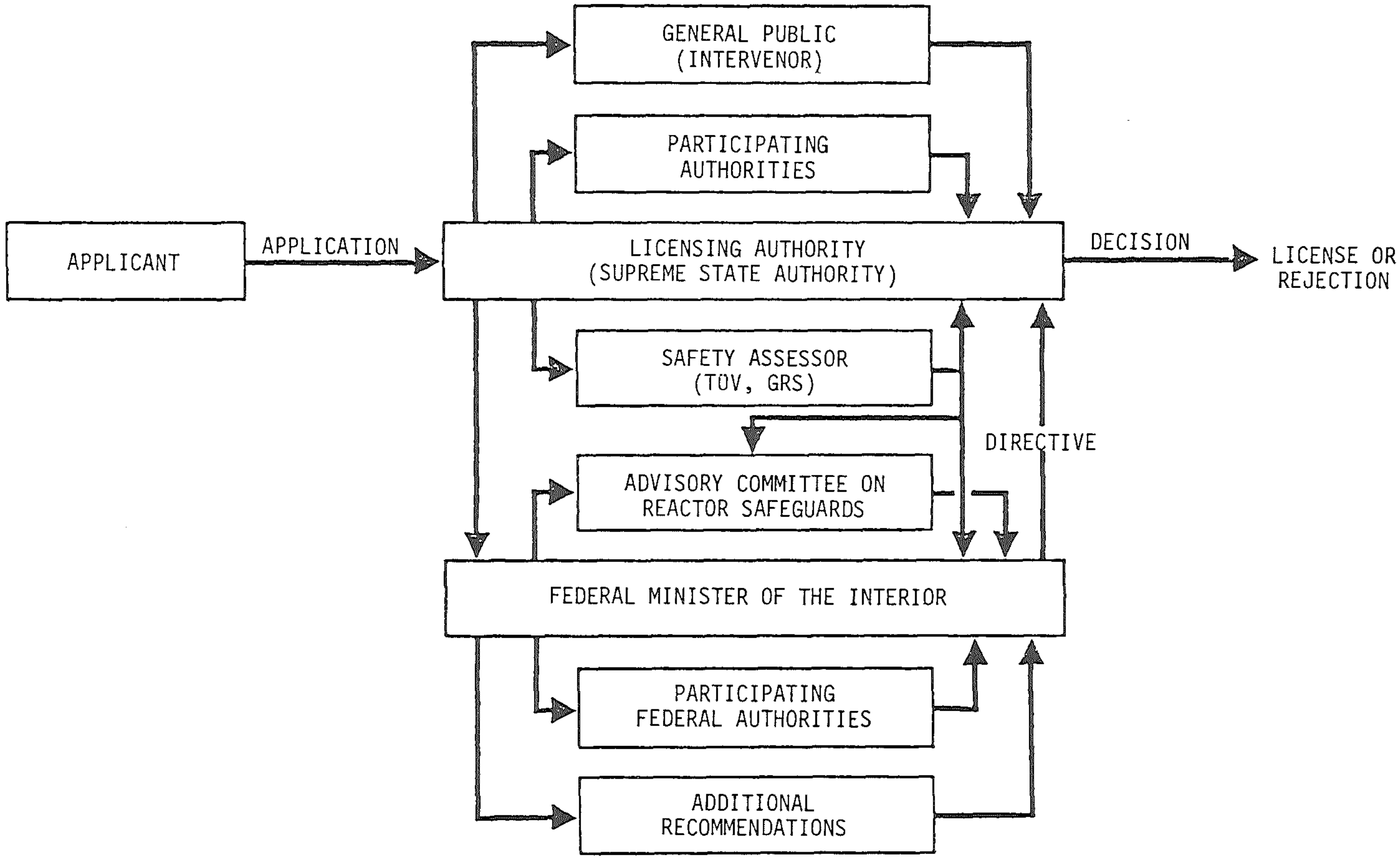


Figure 1: Hierarchy of Regulations and Standards

D	USA	F
Atomic Energy Act	10 CFR 50	
Radiological Protection Ordinance	Appendix I	Decree No 66-450 of 20th June 1966
Safety Criteria for Nuclear Power Plants	Appendix A	Fundamental Safety Rules
KTA Safety Standards RSK Guidelines	Regulatory Guides	Manufacturer Rules
Industrial Norms (e.g. DIN Norms	Technical Standards (ASME, ANSI, IEEE)	

Figure 2: Comparison of National Regulations and Standards (Source: /5/)



<u>Figure 3:</u> Nuclear Licensing Procedure, Participants and their Interaction

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Paper presented at the International Symposium on Safety Codes and Guides (NUSS) in the Light of Current Safety Issues, IAEA, Vienna, 29 October - 2 November 1984

Program of KTA-Safety Standards (June 1986)

Safety Standard	Title	Status[1] (Date of Issue)	English[2] Translation
KTA 1201	Requirements for the Operator Manual	R (12/85)[3]	ip
KTA 1202	Requirements for the Inspection Manual	R (6/84)	
KTA 1301.1	Consideration of the Radiation Protection of Personnel in the Design and Operation of Nuclear Power Plants; Part 1: Design	R (11/84)	
KTA 1301.2	" " "; Part 2: Operation	R (6/82)	ip
KTA 1401	General Requirements for Quality Assurance	R (2/80)	ip
KTA 1402	Quality Assurance in Electrical Engineering	VB	
KTA 1404.1	Method of Documentation During Construction and Operation of Nuclear Power Plants; Part 1: Construction of Nuclear Power Plants	REV	
KTA 1404.2	" " "; Part 2: Operation of Nuclear Power Plants	REV	
KTA 1406	Principles for Certification of Materials used in Nuclear Power Plants	REV	
KTA 1407	Methods for the Determination of Allowable Duration of Maintenance in Nuclear Power Plants	REV	
KTA 1408.1	Quality Assurance for Weld Materials and Weld Additives for Pressure and Activity Retaining Components in Nuclear Power Plants; Part 1: Suitability Testing	R (6/85)	
KTA 1408.2	" " "; Part 2: Manufacture	R (6/85)	
KTA 1408.3	" " "; Part 3: Processing	R (6/85)	
KTA 1501	Stationary System for Monitoring Local Dose Rates within Nuclear Power Plants	R (10/77)	av
KTA 1502.1	Monitoring Radioactivity in the Inner Atmosphere of Nuclear Power Plants; Part 1: Nuclear Power Plants with Light Water Reactors	R (6/86)	
KTA 1502.2	" " "; Part 2: Nuclear Power Plants with High-Temperature Reactors	REV	
KTA 1503.1	Measuring and Monitoring the Discharge of Gaseous and Aerosolbound Radioactive Materials; Part 1: Measuring and Monitoring the Stack Discharge of Radioactive Materials during Specified Normal Operation	R (2/79)	av
KTA 1503.2	" " "; Part 2: Measuring and Monitoring the Stack Discharge of Radioactive Materials during Incidents	REV	
KTA 1503.3	" " "; Part 3: Measuring and Monitoring of Radioactive Materials not Discharged through the Stack	VB	
KTA 1504	Measuring Liquid Radioactive Materials for Monitoring the Radioactive Discharge	R (6/78)	av
KTA 1505	Suitability of Radiation Measurement Equipment	VB	
KTA 1506	Measuring Local Dose Rates in Exclusion Areas of Nuclear Power Plants	R (6/86)	
KTA 1507	Monitoring the Discharges of Gaseous, Aerosolbound and Liquid Radioactive Materials from Research Reactors	R (3/84)	
KTA 1508	Meteorological Instrumentation in Nuclear Power Plants	REV	

1) VB - preliminary report in preparation or issued "Vorbericht"
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3) amended version: replaces version 3/81

Table 1

Program of KTA-Safety Standards (June 1986)

Safety Standard	Title	Status[1] (Date of Issue)	English[2] Translation
KTA 2101.1	Fire Protection in Nuclear Power Plants; Part 1: Basic Principles	R (12/85)	
KTA 2101.2	" " "; Part 2: Structural Components	REV	
KTA 2101.3	" " "; Part 3: Mechanical and Electrical Components	REV	
KTA 2102	Escape and Rescue Routes in Nuclear Power Plants	REV	
KTA 2103	Explosion Protection in Nuclear Power Plants with Light Water and High-Temperature Reactors	RE (6/85)	
KTA 2105	Load Assumptions for Internally Generated Missiles	REV	
KTA 2201.1	Design of Nuclear Power Plants against Seismic Events; Part 1: Basic Principles	R (6/75)	av
KTA 2201.2	" " "; Part 2: Soil Foundation	R (11/82)	ip
KTA 2201.3	" " "; Part 3: Design of Structural Components	REV	
KTA 2201.4	" " "; Part 4: Design of Mechanical and Electrical Components	RE (11/83)	
KTA 2201.5	" " "; Part 5: Seismic Instrumentation	R (6/77)	av
KTA 2201.6	" " "; Part 6: Measures Subsequent to Earthquakes	REV	
KTA 2202.1	Protection of Nuclear Power Plants against Aircraft Crash - Basic Principles and Load Assumptions	REV	
KTA 2203	Protection of Nuclear Power Plants against Aircraft Crash and External Explosions; Design of Structural Components (for given Load Assumptions)	REV	
KTA 2205	Protection of Nuclear Power Plants against the Penetration and Influence of Explosive and Highly Inflammable Materials	VB	
KTA 2206	Design of Nuclear Power Plants against Lightning Effects	REV	
KTA 2207	Protection of Nuclear Power Plants against Floods	R (6/82)	av
KTA 2501	Sealing of Structures in Nuclear Power Plants	RE (6/86)	
KTA 2502	Mechanical Design of Fuel Storage Pools	REV	
KTA 3101.1	Reactor Core Design for Pressurized and Boiling Water Reactors; Part 1: Thermohydraulic Design	R (2/80)	
KTA 3101.2	" " "; Part 2: Nuclear Design	REV	
KTA 3102.1	Reactor Core Design for High-Temperature Gas-Cooled-Reactors; Part 1: Calculation of the Material Properties of Helium	R (6/78)	av
KTA 3102.2	" " "; Part 2: Heat Transport in Spherical Fuel Elements	R (6/83)	
KTA 3102.3	Reactor Core Design for High-Temperature Gas-Cooled Reactors; Part 3: Loss of Pressure through Friction in Spherical Fuel Element Piles	R (3/81)	
KTA 3102.4	" " "; Part 4: Thermohydraulic Analytical Model for Stationary and Quasi-Stationary Conditions in Spherical Fuel Element Piles	R (11/84)	
KTA 3102.5	" " "; Part 5: Systematic and Statistical Errors in the Thermohydraulic Core-Design of the Pebble-Bed Reactor	R (6/86)	
KTA 3103	Shutdown Systems of Light Water Reactors	R (3/84)	
KTA 3104	Determination of the Shutdown Reactivity	R (10/79)	

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Table 1 (contd.)

Program of KTA-Safety Standards (June 1986)

Safety Standard	Title	Status[1] (Date of Issue)	English[2] Translation
KTA 3200	Safety Requirements for Nuclear Coolant Systems in Nuclear Power Plants with Light Water Reactors	REV	
KTA 3201.0	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; General Part	REV	
KTA 3201.1	" " "; Part: Materials	R (11/82)[3]	ip
KTA 3201.2	" " "; Part: Design and Analysis	R (3/84)[4]	ip
KTA 3201.3	" " "; Part: Manufacture	R (10/79)	ip
KTA 3201.4	" " "; Part: Inservice Inspections and Operational Monitoring	R (6/82)	ip
KTA 3203	Monitoring Radiation Embrittlement of Materials of the Reactor Pressure Vessel of Light Water Reactors	R (3/84)	ip
KTA 3204	Reactor Pressure Vessel Internals	R (3/84)	
KTA 3205.1	Component-Support Structures with Non-integral Connections; Part 1: Component-Support Structures with Non-integral Connections for Components of the Reactor-Coolant Pressure Boundary	R (6/82)	ip
KTA 3205.2	" " "; Part 2: Component-Support Structures with Non-integral Connections for Pressure and Activity Retaining Components outside the Reactor Coolant Pressure Boundary	REV	
KTA 3205.3	" " "; Part 3: Standard Supports	REV	
KTA 3211.1	Pressure and Activity Retaining Components of Systems outside the Reactor Coolant Pressure Boundary; Part: Materials	REV	
KTA 3211.2	" " "; Part: Design and Analysis	REV	
KTA 3211.3	" " "; Part: Manufacture	REV	
KTA 3211.4	" " "; Part: Recurrent Tests	REV	
KTA 3301	Residual-Heat Removal Systems for Light Water Reactors	R (11/84)	
KTA 3302	Requirements for Pressure Relief Valves of the Primary and Secondary Circuit	REV	
KTA 3303	Heat-Removal Systems for Water-Cooled Fuel Element Storage Pools in the Reactor Building of Nuclear Power Plants with Light Water Reactors	REV	
KTA 3304	Measures for Closure of Pipes of Systems in Case of System-Internal Incidents	VB	
KTA 3401.1	Steel Containment Vessels; Part: Materials	R (11/82)	ip
KTA 3401.2	" " "; Part: Analysis and Design	R (6/85)[5]	ip
KTA 3401.3	" " "; Part: Manufacture	R (10/79)	ip
KTA 3401.4	" " "; Part: Recurrent Tests	R (3/81)	ip
KTA 3402	Air Locks through the Containment Vessel of Nuclear Power Plants - Personnel Locks	R (11/76)	av

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3) amended version: replaces version 2/79

4) amended version: replaces version 10/80

5) amended version: replaces version 6/80

Table 1 (contd.)

Program of KTA-Safety Standards (June 1986)

Safety Standard	Title	Status[1] (Date of Issue)	English[2] Translation
KTA 3403	Cable Penetrations through the Reactor Containment Vessel	R (10/80)[3]	ip
KTA 3404	Closure of Pipe Penetrations through the Containment in Case of a Release of Radioactive Materials inside the Reactor Containment	RE (6/77)	
KTA 3405	Integral Leakage Rate Testing of the Containment Vessel with the Absolute Pressure Method	R (2/79)	ip
KTA 3406.1	Measurement and Control of the Hydrogen Concentration in the Containment Vessel; Part 1: Measurement	REV	
KTA 3406.2	" " "; Part 2: Control	REV	
KTA 3407	Pipe Penetrations through the Reactor Containment Vessel	RE (6/85)	
KTA 3409	Air Locks through the Containment Vessel for Nuclear Power Plants - Material Locks	R (6/79)	ip
KTA 3413	Determination of the Loads for the Design of the Large Dry Containment against Plant-Internal Incidents	RE (12/85)	
KTA 3501	Reactor Protection System and Monitoring Equipment of the Safety System	R (6/85)[4]	ip
KTA 3502	Incident Instrumentation	R (11/82)	
KTA 3503	Type Testing of Electrical Modules for the Reactor Protection System	R (6/82)	av
KTA 3504	Electrical Drives of the Safety System in Nuclear Power Plants	RE (11/84)	
KTA 3505	Type Testing of Measuring Transmitters and Transducers of the Reactor Protection System	R (11/84)	
KTA 3506	Tests of Electrotechnical Control Systems of the Safety System of Nuclear Power Plants	R (11/84)	
KTA 3507	Factory Tests of Equipment for Instrumentation and Control	RE (11/82)	
KTA 3601	Ventilation and Air Filtration Systems in Nuclear Power Plants	RE (10/79)	
KTA 3602	Storage and Handling of Nuclear Fuel Elements, Control Rods, and Neutron Sources in Nuclear Power Plants with Light Water Reactors	R (6/84)[5]	
KTA 3603	Facilities for Treating Radioactively Contaminated Water in Nuclear Power Plants	R (2/80)	ip
KTA 3604	Storage, Handling and Plant-Internal Transportation of Radioactive Materials (other than Nuclear Fuel Elements) in Nuclear Power Plants	R (6/83)[6]	
KTA 3605.1	Gas Exhaust Systems of Nuclear Power Plants; Part 1: Light Water Reactors	REV	
KTA 3605.2	" " "; Part 2: High-Temperature Gas-Cooled Reactors	VB	
KTA 3605.3	" " "; Part 3: Fast Breeder Reactors	VB	
KTA 3606	Concentrated Radioactive Wastes in Nuclear Power Plants	REV	

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3) amended version: replaces version 11/76

4) amended version: replaces version 3/77

5) amended version: replaces version 6/82

6) amended version: replaces version 11/82

<u>Table 1</u> (contd.)

Program of KTA-Safety Standards (June 1986)

Safety Standard	Title	Status[1] (Date of Issue)		English[2] Translation
KTA 3607	Quantitative In-Situ Testing of Aerosol Filters	REV		
KTA 3701.1	General Requirements for the Electrical Power Supply of the Safety System in Nuclear Power Plants; Part 1: Single-Unit Plants	R	(6/78)	av
KTA 3701.2	" " "; Part 2: Multi-Unit Plants	R	(6/82)	
KTA 3702.1	Emergency Power Facilities with Diesel Generators; Part 1: Design	R	(6/80)	ip
KTA 3702.2	" " "; Part 2: Tests and Examinations	R	(11/82)	
KTA 3703	Emergency Power Facilities with Batteries and Rectifiers	R	(6/86)	
KTA 3704	Emergency Power Facilities with DC/AC Converters	R	(6/84)	
KTA 3705	Switching and Distributor Facilities in Emergency Power Facilities	REV		
KTA 3706	Resistance of Electrical Equipment for Incident Conditions	REV		
KTA 3901	Communication Systems for Nuclear Power Plants	R	(3/81)[3]	ip
KTA 3902	Lifting Equipment in Nuclear Facilities	R	(11/83)[4]	ip
KTA 3903	Testing and Operation of Lifting Equipment in Nuclear Facilities	R	(11/82)	
KTA 3904	Control Room and the Emergency and Local Control Facilities in Nuclear Power Plants	RE	(6/85)	
KTA 3905	Design, Testing and Inspection of Load Suspension Points in Nuclear Facilities	REV		

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3) replaces KTA 3901.1 version 3/77

4) amended version: replaces version 6/78

Table 1 (contd.)

In-Service Inspection, Prerequisite for high NPP Availability and Safety

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Introduction

For nuclear power plant (NPP) availability and safety there exist a series of important contributors

- a proven design

- comprehensive quality assurance during manufacturing and construction

- qualified plant monitoring for early stage failure detection

- in-service inspection (ISI) during plant operation to demonstrate a continuously high level of component quality or to enable adequate repair measures and

- as an overall item the provision of adequately qualified personnel for all these tasks mentioned above.

Although this paper concentrates on ISI and its effects on plant availability the interconnection to the other areas listed also has to be considered. In-service inspection includes

- cost lowering and effective procedures during plant shut-down and radiation exposure of components and systems used

- man power which may have to work under radiation exposure as low as reasonably achievable

- requirements with respect to scheduling for preparative work, performance of inspections and useful evaluation and

- a comprehensive documentation of all relevant data which have to be available over power plant life time.

There exist different regulations or standards on ISI e.g. the Safety Guide on In-Service Inspection for Nuclear Power Plants (IAEA Safety Series No. 50-SG-02), German KTA Safety Standards or ASME XI. These guidelines are valid for different nuclear power plant concepts but this paper concentrates on examples taken from pressurized light-water reactors in the german power plant design concept by KWU. Similar procedures exist in other countries as /1/ shows.

ISI Effects on Design and Manufacturing

As in-service inspection routines for PWRs concentrate on reactor pressure components to ensure the safe enclosure of radioactive fission products and activated matter like corrosion products and coolant within the primary circuit, the respective components have undergone a risk reducing development /2/.

To achieve the high technical level of the new concept of pressure-retaining components a systematic and continuous development in fields as materials, fabrication, design and calculation was necessary. Considerable progress has been made in the production of heavy forgings during recent years resulting in optimized construction of the components. The number of seam welds could be extensively reduced leading to the following essential advantages:

- The operational safety has gradually been increased since, with the reduction of the seam welds, the probability of remaining flaws is reduced.

- The manufacturing risk has been decreased since the defect frequency is greater in seam welds than in the base material.

- The scope of non-destructive examination has been reduced during fabrication as well as during in-service inspections.

- The fabrication times have been shortened.

Figures 1 to 5 /2/ show the improvements achieved for individual components. It ought to be mentioned that the change from the "old" to the "new" design status has been progressive and was not a sudden step. The figures showing the saving in seam weld numbers are valid for standardized pressurized water reactors with an output of 1300 MW(e):

- The total length of seam welds of 122 m for the reactor pressure vessel has been reduced to one half, that is to 61 m (Fig. 1).

- On the secondary shell of the steam generators, seam welds of 50 m length were saved, i.e. 200 m for the four steam generators of one plant (Fig. 2).

- The new main coolant pump housings are forged in one piece. Seam welds are completely avoided (Fig. 3).

- The entire seam weld length of the pressurizer has been reduced to approximately a third, from 91 m to 28 m (Fig. 4).

- The nozzles of the main coolant pipes are manufactured as an integral element of the forged straight pipes. The pipe elbows, formerly welded together from two half shells, are formed to seamless elbows with forged tubes as initial material (Fig. 5). With these two measures the total number of seam welds is reduced from 250 to 60 circumferential joint welds.

Figures 1 to 5 also show that by the exclusive use of forging the requirement of a mechanical design that is adequate to the loads to which the components will be subjected in service is fulfilled to a high degree. Local peak stresses are avoided by smooth shaping and seam welds are located in areas of low stresses.

Additional efforts to minimize the number of welds in the primary pressure boundary are illustrated in the comparison given in Fig. 6. Considerable improvements have been achieved in the quality of the primary piping. The above mentioned forged-on nozzles are used for major attachment of the more important systems like volume control and emergency core cooling as well as sections of piping bent in more than one plane. The savings in the amount of welding at site are considerable, so are the benefits for in-service inspection.

These design improvements in the primary pressure boundary have brought also some progress in the regulatory requirements. Rather than specifying engineered countermeasures to limit propagation and consequences of accidents (which meant extensive pipe whip restraints and poor access to the piping itself) greater emphasis is now placed on accident prevention (which means surveillance of the built-in quality over the years) and on reduction of radiation exposure.

Not only the components to be inspected have been improved but also the whole NPP design was subject for introducing features for facilitating operational and inspection activities. As inspection starts in many cases with a visual examination, the accessibility e.g. inside the containment as shown in Fig. 7 is of importance. Together with an adequate positioning of auxiliary equipment, instrumentation etc. this leads once more to substantial man-dose reduction. Sufficient space for equipment storage and handling is of importance especially if work can be prepared without shutting down the plant and thereby increasing the overall availability.

As operational experience of NPP shows, an important percentage of non-availability increasing defects originate from corrosion e.g. in the steam generators by stress or crevice corrosion on the secondary side.

In Fig. 8 a simplified scheme of the essential components of the secondary system of a pressurized water reactor plant is shown. The main features of KWU's secondary-side concept are listed in the three boxes on the right-hand side. This concept minimizes the ingress of corrosion products and impurities into the steam generators, which can be considered as the most sensitive components of the PWR.

The operating experience gained with KWU steam generators is extremely satisfactory. The most important reason is the selection of Incoloy 800 as tube material which drastically minimizes the risk of stress corrosion. Furthermore, the possibility of tube denting is completely ruled out by the use of egg-crate type support grids made of stabilized austenitic stainless steel.

By virtue of specially adapted manufacturing specifications and design, crevice corrosion on tubes in the vicinity of the tubesheet and also the well-known problems of fretting damage encountered by other suppliers are ruled out.

Corrosion product ingress via the blowdown line is reduced by means of annual lancing using a high-pressure spraying technique. This minimizes the risks of the build-up of a highly corrosive layer on top of the tubesheet. Consequently, all the other measures, shown in the boxes on the right-hand side, are also geared to the reduction of contaminant ingress into the secondary system:

- Installation of a high integrity condenser with copper-free tube material resistant to corrosion/erosion e.g. titanium, tube to tubesheet welding and an improved condenser leakage monitoring system, and
- Use of electromagnetic and mechanical filters in the feedwater line and de-aeration of feedwater, as well as
- Chemistry control by virtue of the installation of sensitive sodium and chlorine monitors.

All these measures allow optimum secondary-side water chemistry with high all volatile treatment and appropriate pH values greater than or equal to 9.8.

Measures such as the secondary side concept to increase the overall availability of NPPs are combinations of design oriented preventions and operational monitoring procedures and considered here as ISI relevant. Therefore in the following the monitoring concept also has to be included as an in-operation ISI part.

Monitoring System for NPPs

As the total amount of ISI work not only depends on regularly planned inspections but also on failures which have been detected e.g. between two refuelling periods or which caused immediate inspection and repair work, a sensitive monitoring system /3/ is an important prerequisite for effective ISI.

Such systems represent an instrumentarium for the earliest possible detection of anomalies and malfunctions in machines, piping systems and tanks, as well as their internals. The mode of operation of most of the individual systems presented here is based on the detection and analyis of mechanical-dynamic signals at frequencies between 0.1 Hz and 1 MHz, others work with thermal signals.

Common design aspects of such monitoring systems are:

- integral surveillance by a limited number of reliable sensors, mostly on the outside of the components
- special indirect measuring methods with sophisticated signal analysis (e.g. of noise)
- microprocessor systems with intelligent software for alarm annunciation and the capacity of complete data storage especially for the pre-failure history
- adequate documentation.

Fig. 9a gives on overview of the current monitoring systems developed and operated by KWU:

- Change in operating noises such as the impact of loose parts or detached parts banging on vessel walls (e.g. steam generators and reactor pressure vessels in nuclear power plants)
  (By means of the loose parts monitoring system LPMS)
- Changes in the oscillation behaviour of machines, vessels and piping systems
  (By means of the vibration monitoring system VMS)
- Internal and external leaks
  (By means of the acoustic leakage monitoring system ALMS)

- The thermal stratification monitoring system (TSMS)
- Component fatigue as a result of thermal stresses
  (By means of the fatigue monitoring systems FAMOS)
- Origination and propagation of cracks
  (By means of the crack monitoring system CMS)
- The seismic detection system (SDS).

For example, the LPMS is an established monitoring system and installed in all KWU reactors. Cases of detected parts demonstrate the high sensitivity of the system (impacts of a 10 g mass) and the capabilities to localize and to distinguish between loosened and detached parts. The modular, microprocessor-based system (see Fig. 9b) was completed and first installed in the nuclear power station Brokdorf in the north of Germany near Hamburg.

The application of such systems are far from being restricted to nuclear power plant operation. They can be employed in all facilities and technical structures in which malfunctions or failures represent a safety hazard or economic risk - e.g. tanks and containers in the petrochemical industry, large machines or means of transport.

ISI Techniques and Equipment

The development of ISI methods, techniques and equipment in Germany was based on the requirements (KTA Safety Standards) for Class 1 components. These safety standards require more details and more frequent coverage than specified for example in ASME XI. This has resulted in an almost 100 % mechanization of the examinations of the reactor coolant system components and piping of PWR plants which was followed by a considerable reduction of the radiation exposure of examination personnel. Mechanized, remote controlled testing equipment has been developed which is set up on a permanently installed rail system shown schematicly in Fig. 10 and corresponding to the new seam weld concept and the extensive use of forged pipe elements mentioned above in the design relevant ISI consequences.

For the reactor pressure vessel (RPV) additional equipment is used for inspection at regular intervals, normally every 4 years. The transducers and search units required for inspection purposes, for example ultrasonic probes, are brought into position in the reactor pressure vessel with the aid of center mast manipulators (Fig. 11a, 11b).

Center mast manipulators are large equipment units which, in conjunction with special tools, make it possible to subject pressure vessels, nozzles and internals to

- visual inspection via closed-circuit television
- ultrasonic and eddy-current testing and
- repair measures.

As Fig. 11b shows, significant reduction in inspection time (about - 30 %) and radiation exposure (about - 50 %) have been achieved in RPV-ISI using the new central mast manipulator CMM3 and specially developed tools for the different inspection tasks.

The extension of service in the case of the steam generator tube inspection was linked with the problem that the water level in the reactor pressure vessel had to be lowered during the time the steam generator primary channel heads were open and no servicing work could thus be carried out due to the lack of shielding. To this end, loop seal units have been developed which plug the primary system pipes on the reactor pressure vessel and permit simultaneous work in the steam generator channel heads and in the reactor pressure vessel at an elevated water level (Fig. 11c).

Time scheduling for refueling and major inspection in Fig. 12 shows that the inspection of steam generators, besides the checks of fuel assemblies, dominate the shut down period. Control of steam generator tubes was manpower consuming in the past and resulted in significant radiation doses.

Various measures have been provided in the past decade to reduce working time and radiation exposure:

- remote controlled devices like finger walkers (see Fig. 13 and 14) have been developed and improved for automatic inspection procedures

- the change from the manual insertion of explosively welded tube plugs to reusable tube plugs and automatic insertion brought a drastic reduction in radiation dose per plug insertion as Fig. 13 shows in the lower part.

The application of finger walkers for remote controlled steam generator tube testing allows different procedures /4/ during testing activities, e.g.:

- analysis and/or visual examination by endoscopes and

- combined eddy-current (ET) and ultra sonic (UT) testing (Fig. 15a)

or tube repair, e.g.:

- removal of excess weld material and

- plugging defective tubes with reusable plugs as shown in Fig. 15b.

The effective use of remote techniques is clearly documented by the evaluation of work done between 1980 and 1984. In Fig. 16 a compilation of inspected steam generator, tubes and exposure specific working time is given. The progress achieved is obvious.

Final Remarks

Although standardization has been achieved in many areas, important driving forces behind nuclear power plant development still exist. These are e.g.:

- reduction of investment and operating costs, the latter mainly by increasing plant availability (Fig. 17),

- automation of operation,

- reduction of the personnel radiation exposure,

- perfection of service activities by special handling tools and procedures, and
- improvement in the fuel cycle area.

Except the last item, all others are more or less interconnected to in-service inspection procedures. These are not only restricted to the reactor area. Therefore it has been the policy of many suppliers to focus not only on the nuclear steam supply system but also on the entire power plant with its multi-faceted interplay of functions. KWU for example has therefore assumed full responsibility for all its german nuclear power plants in respect of planning, engineering, erection and commissioning.

In this paper the relations between ISI activities, design, regulations and standards and plant operation have been shown. The ISI region has been widened to include monitoring and special operational procedures leading to higher plant availability and safer operation.

References

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/3/ P. Jax, K. Ruthrof, K. Riedle: Early Failure Monitoring System for LWR Operation, Kraftwerk-Union Erlangen

/4/ K. Fischer, H. Kaste, M. Kurzawe: Dose Reduction by Application of Advanced Methods for Testing and Repairing of Steam Generator Tubes, Proc. 5. Int. Meet. Thermal Nuclear Reactor Safety, Karlsruhe, 9-13 Sept. 1984, Vol. 1, KfK-3880/1, Dec. 1984, pp 273-282.

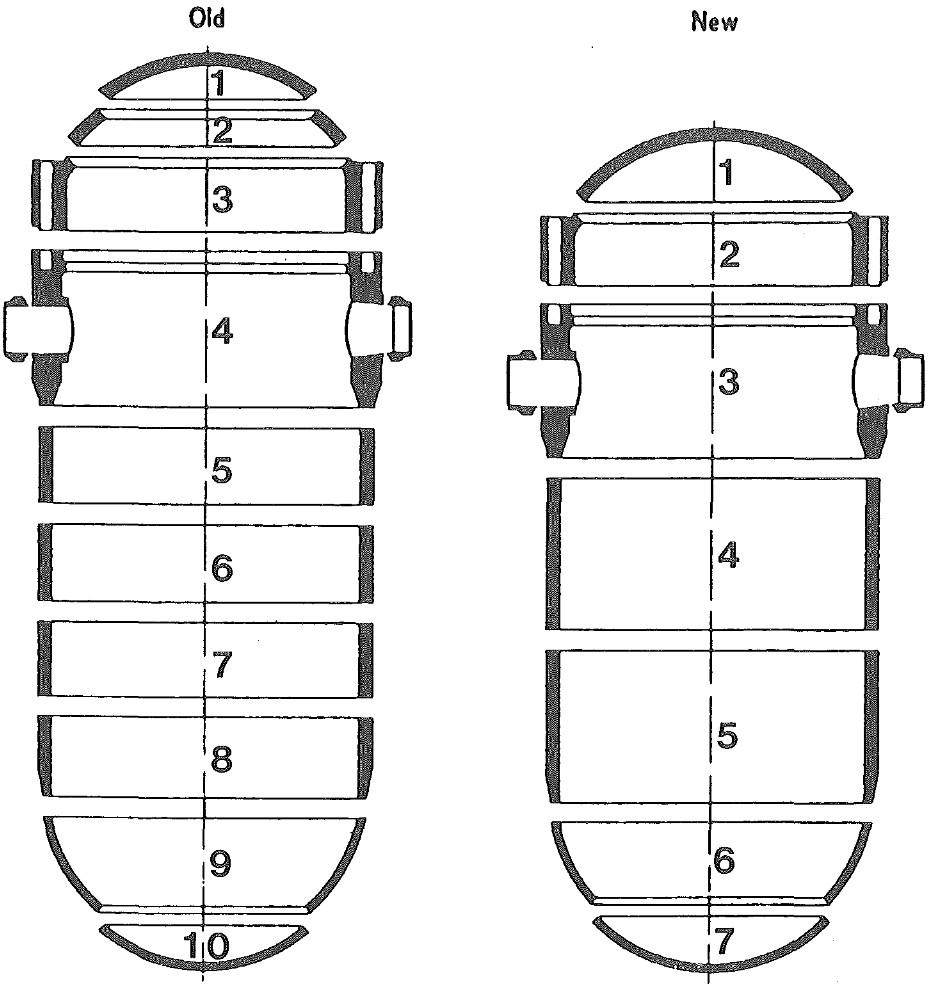


FIG.1. Forgings for reactor pressure vessels of 1300 MW(e).

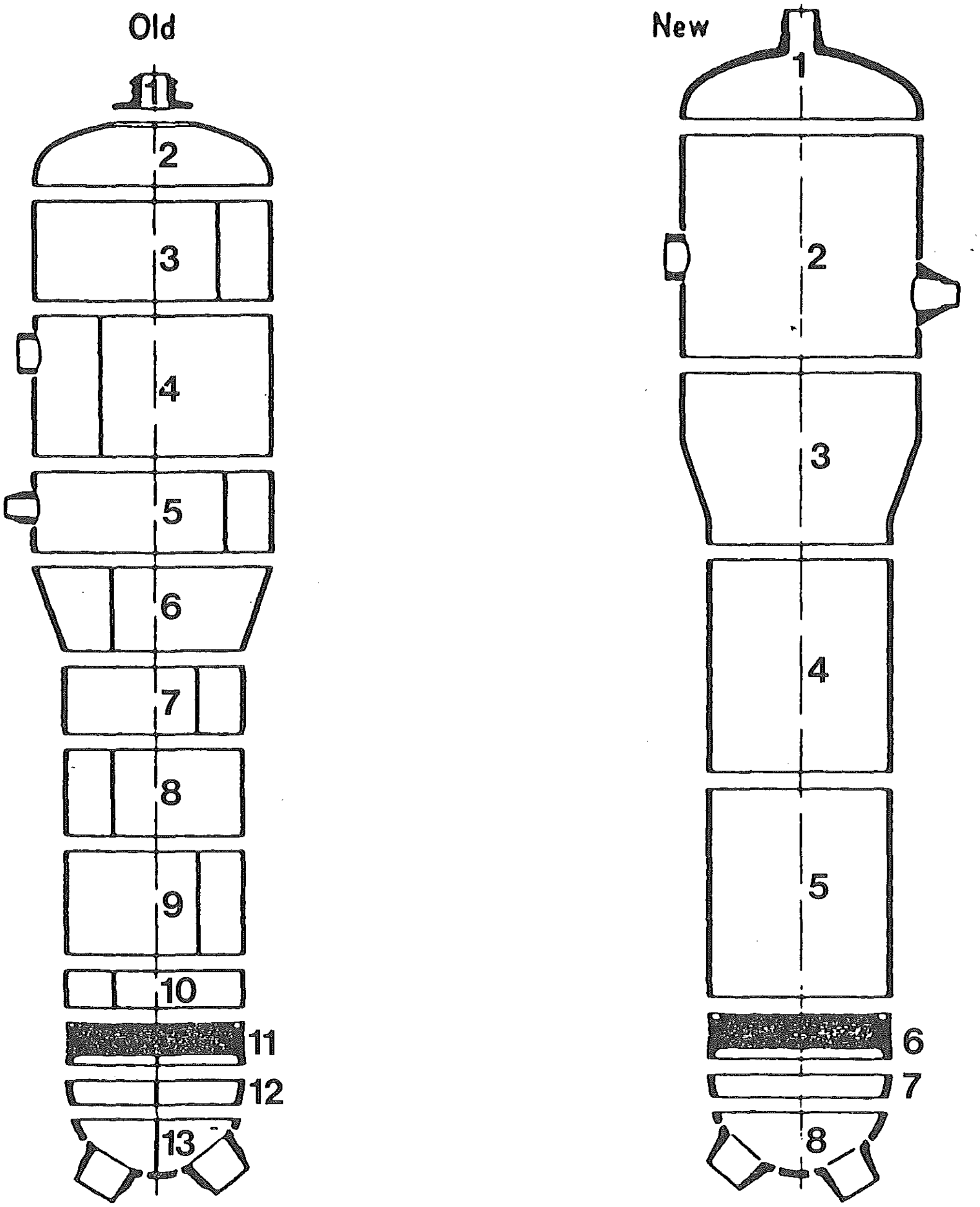


FIG.2. Pressure-retaining parts for steam generators.

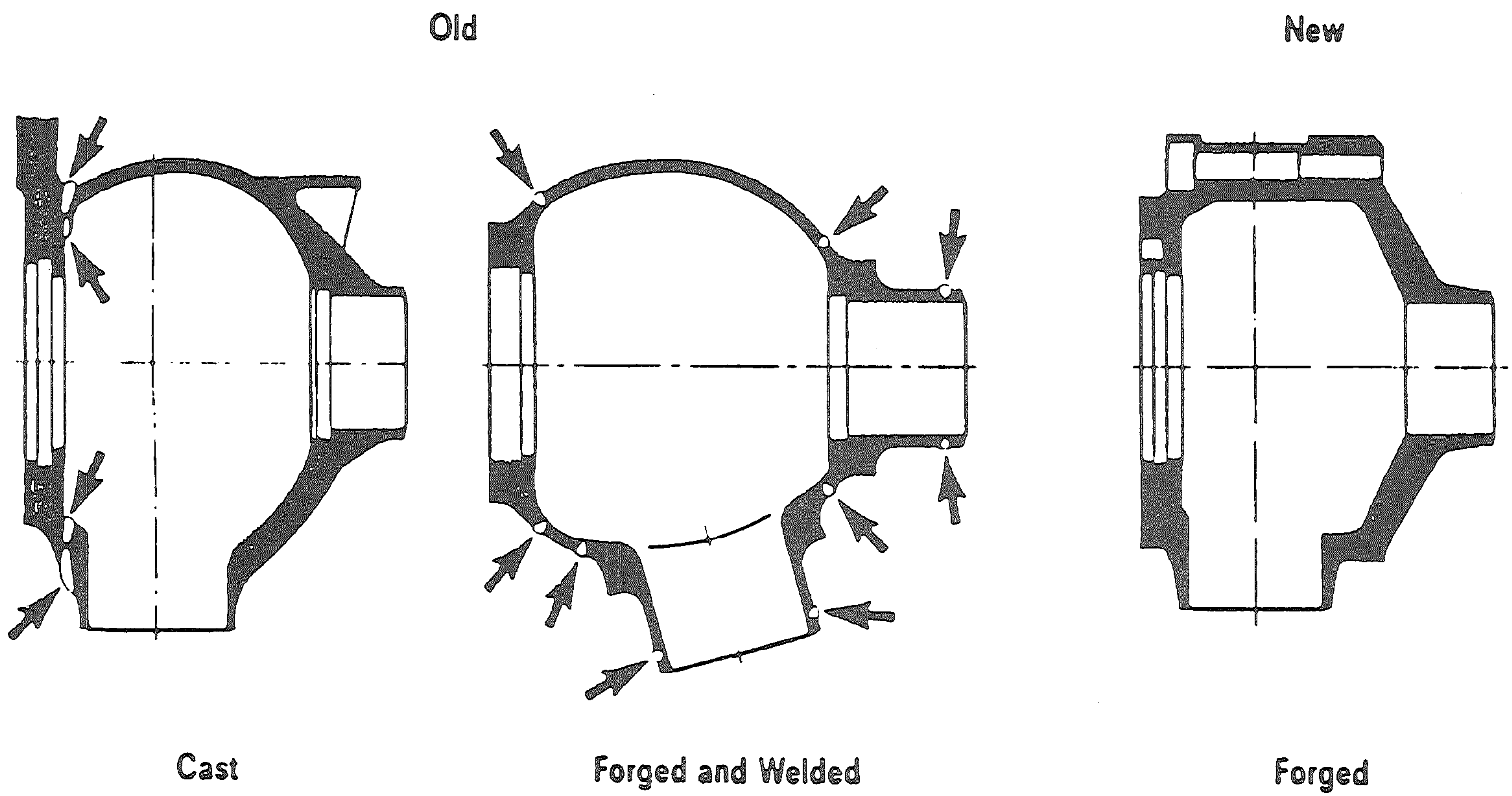


FIG.3. Housing for reactor coolant pumps.

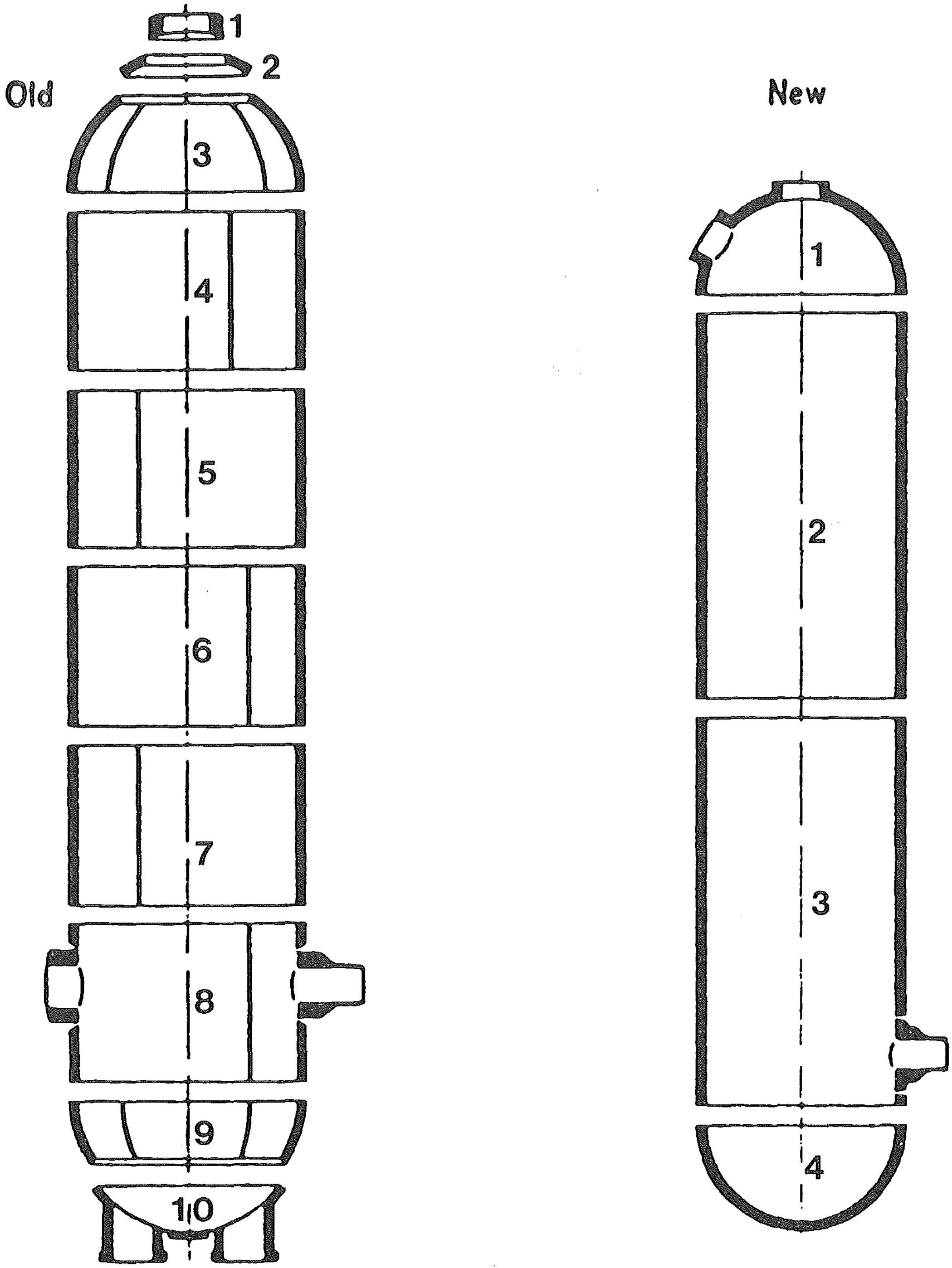


FIG.4. Pressure-retaining parts for pressurizer.

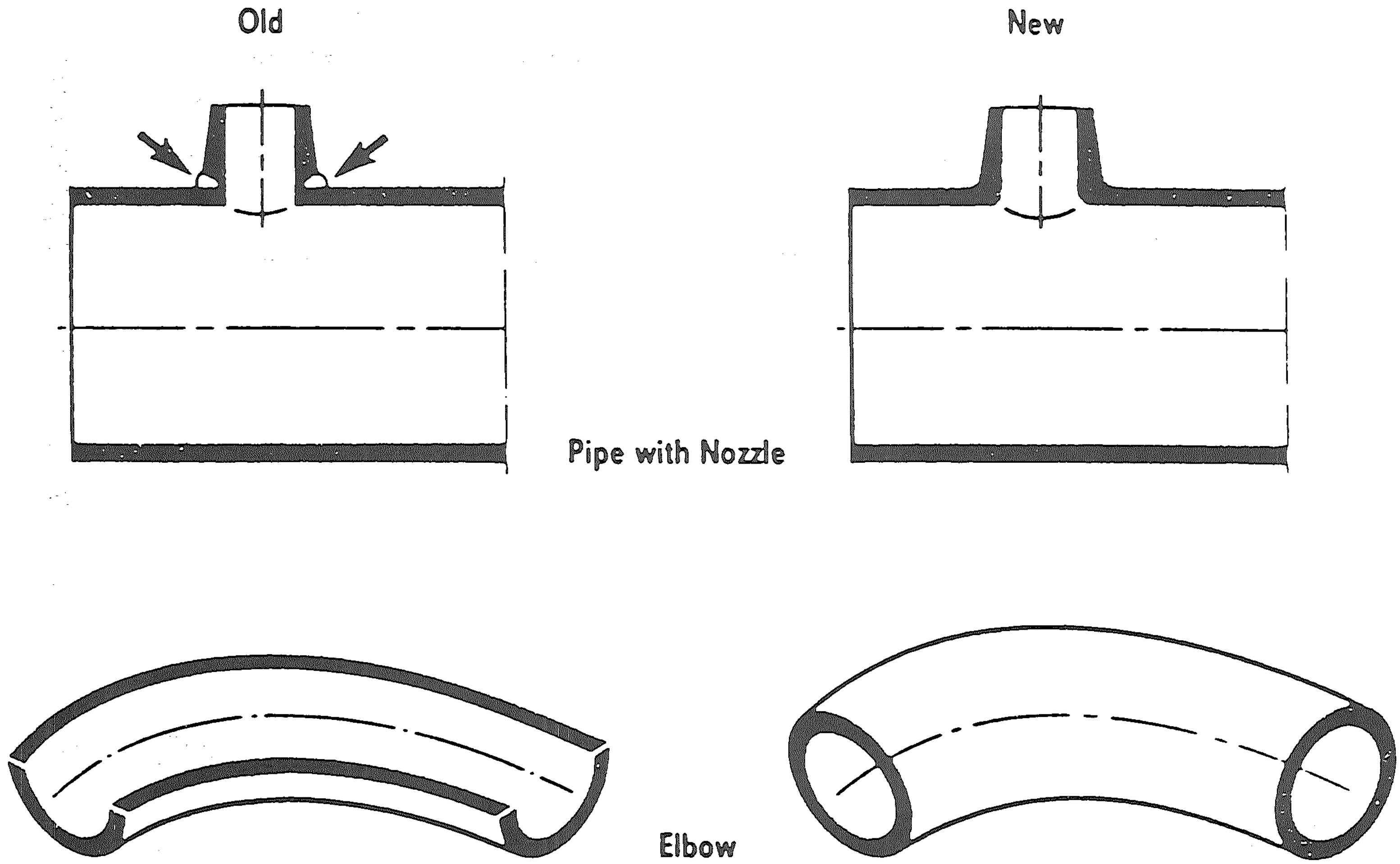
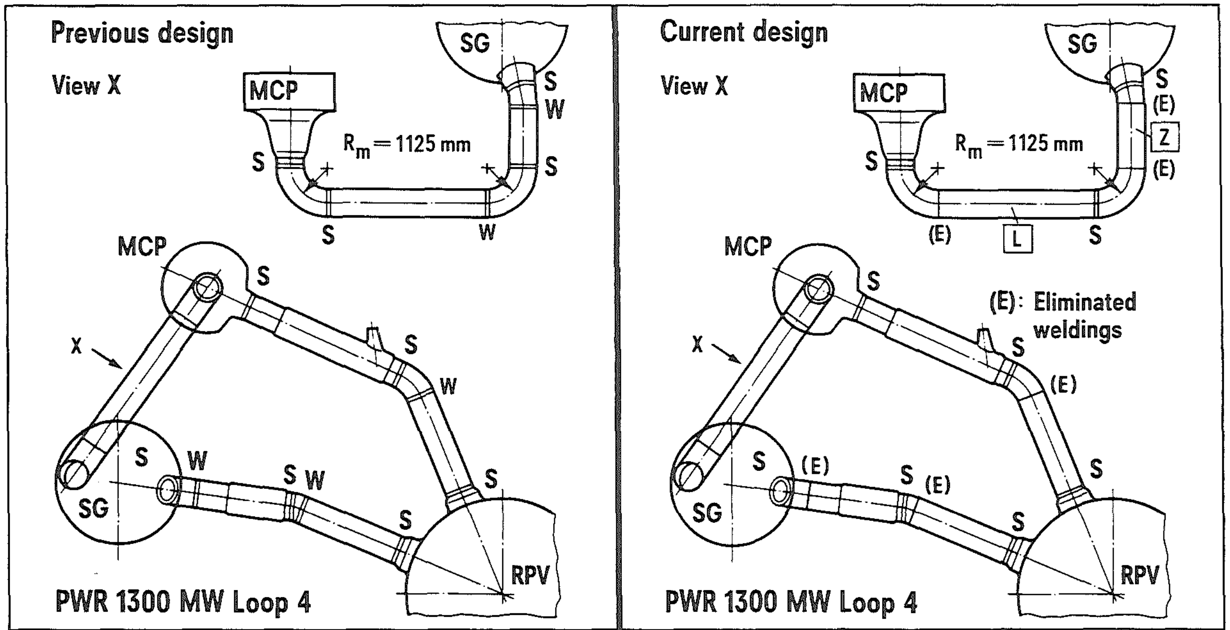


FIG.5. Elements for main coolant pipes.

Fig. 6



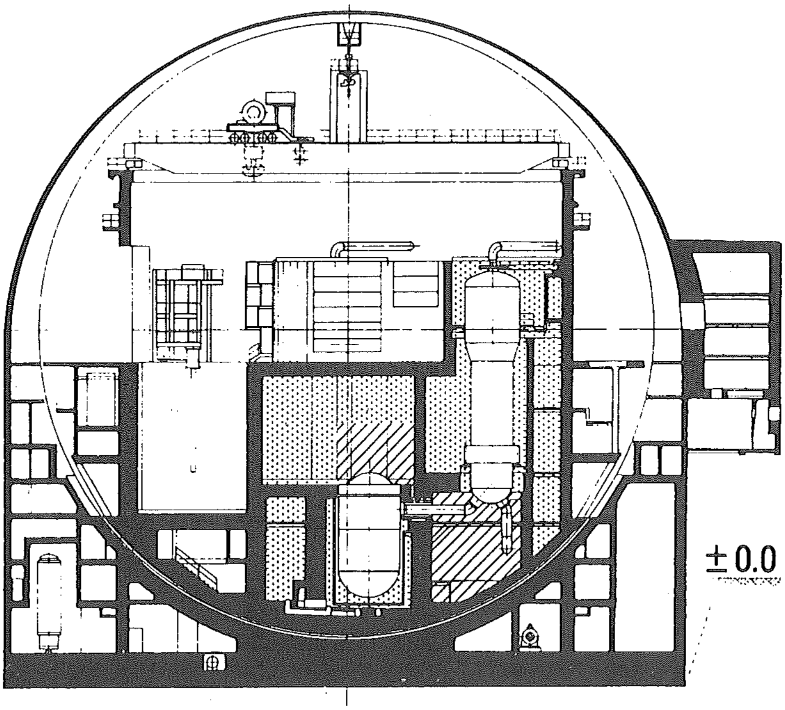
Previous design	Current design
4 x 5 = 20 Workshop weldings 4 x 10 = 40 Site weldings	4 x 9 = 36 Site weldings
Total: 60 Circumferential weldings	Total: 36 Circumferential weldings

S Site welding W Workshop welding L L-Shaped Pipe segment Z Z-Shaped Pipe segment

Possibilities to Save Circumferential Weldings of the Main Coolant Pipe

E831079 Ce

Fig. 7 KWU



Advantages:

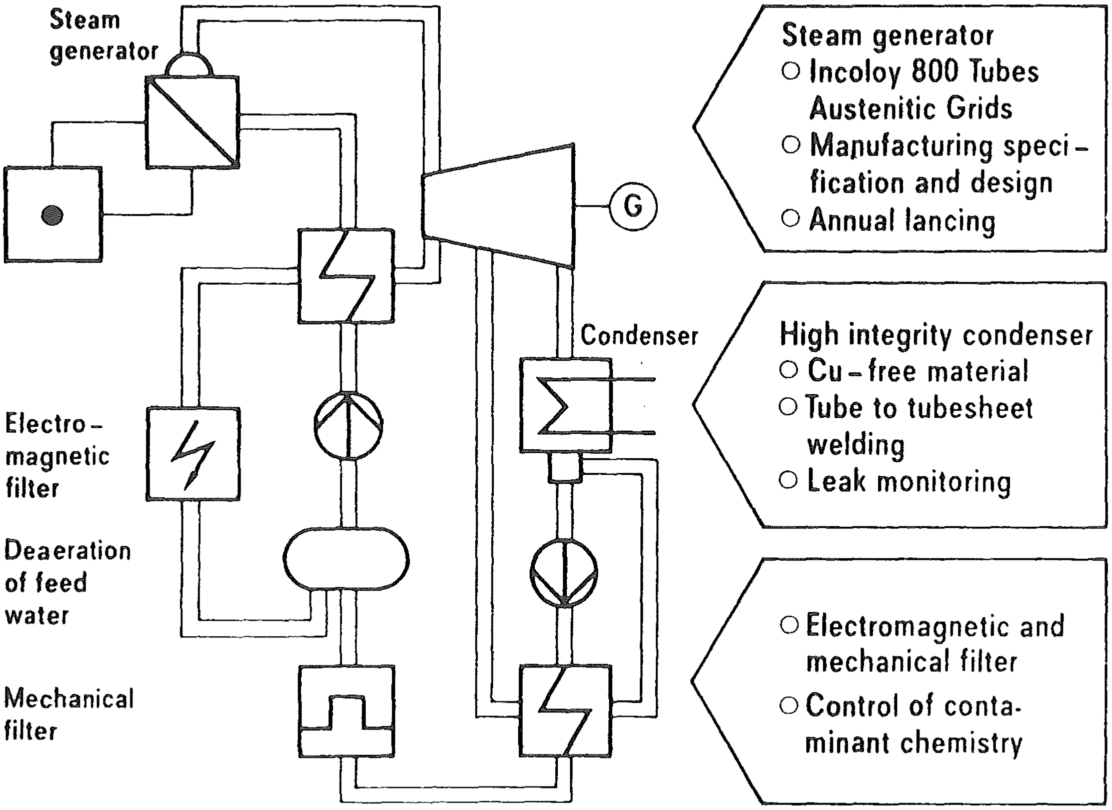
- Accessible during operation
- Ample space for laydown and servicing
- Spent fuel pool adjacent to reactor well

▨ Not accessible during operation
░ Limited accessible during operation

Design Features Facilitating Inspection Activities

E 84 2079 Ce

Fig. 8

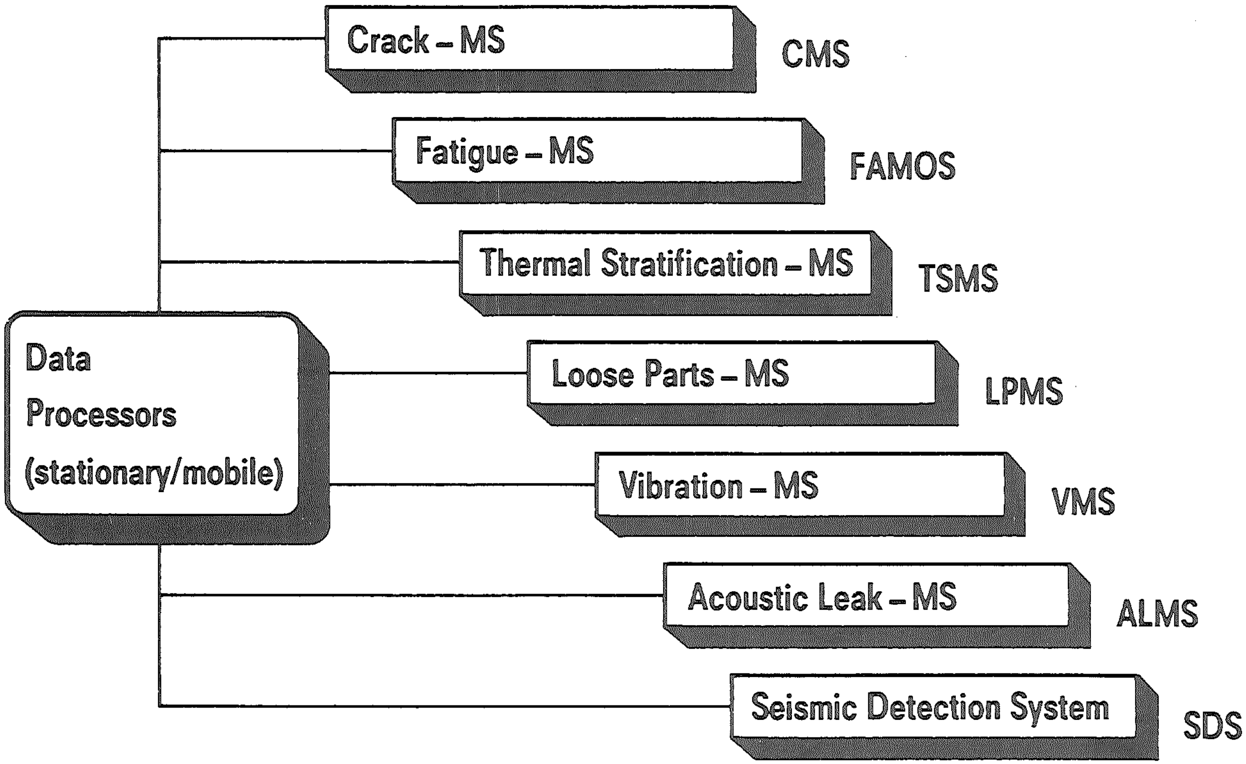


allows optimum secondary-side water chemistry

High All Volatile Treatment (H-AVT)
pH $\geqq$ 9.8

PWR Systems and Components –
Main Features of KWU's Secondary-Side Concept to Reduce Ingress of Corrosion Products and Impurities into Steam Generators

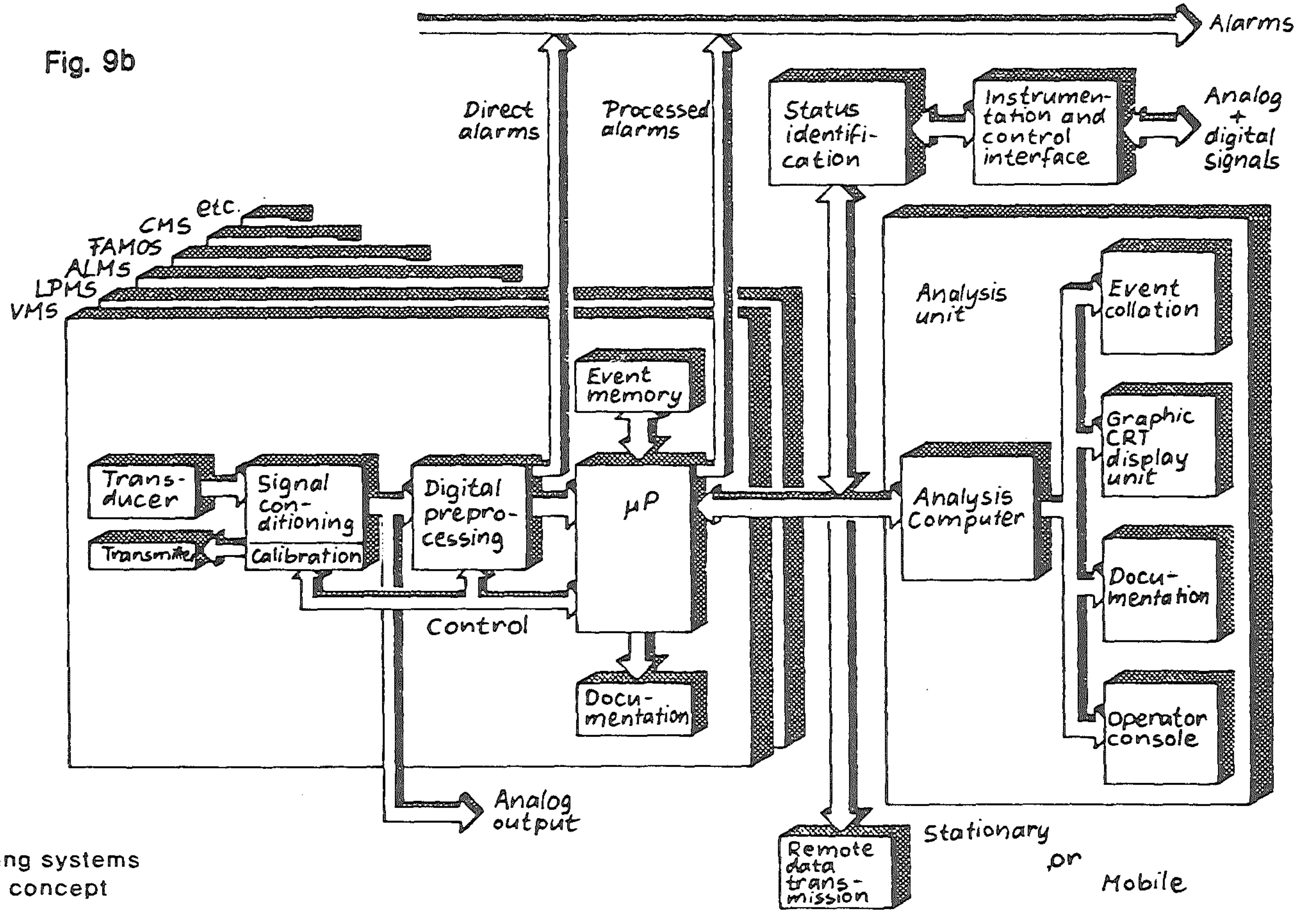
E84465Ce



Monitoring Systems (MS) for Nuclear Power Plants

E 85 436 Ce

Fig. 9b



Monitoring systems
Modular concept

Published by Kraftwerk Union AG
Wiesenstraße 35, D-4330 Mülheim an der Ruhr

Vibration monitoring system (VMS)
Loose parts monitoring system (LPMS)
Acoustic leakage monitoring system (ALMS)
Fatigue monitoring system (FAMOS)
Crack monitoring system (CMS)
etc.

1 Platform
2 Rail supports for circumferential and longitudinal welds
3 Rail for circumferential welds
4 Rail for longitudinal welds
5 Removable rail for manhole nozzles
6 Rail for RCL circumferential welds
7 Swivel-mounted rail for RCL circumferential and longitudinal welds
8 Permanent insulation
9 Removable insulation panel

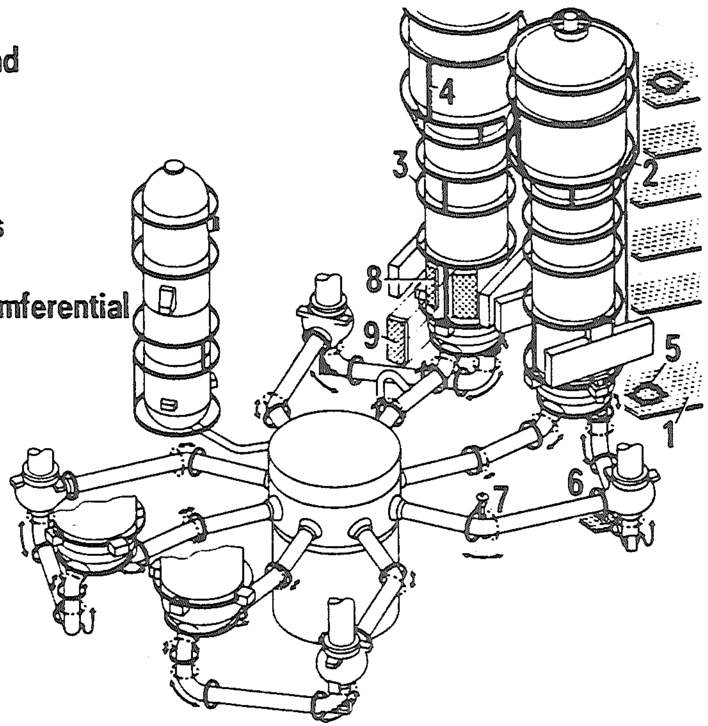


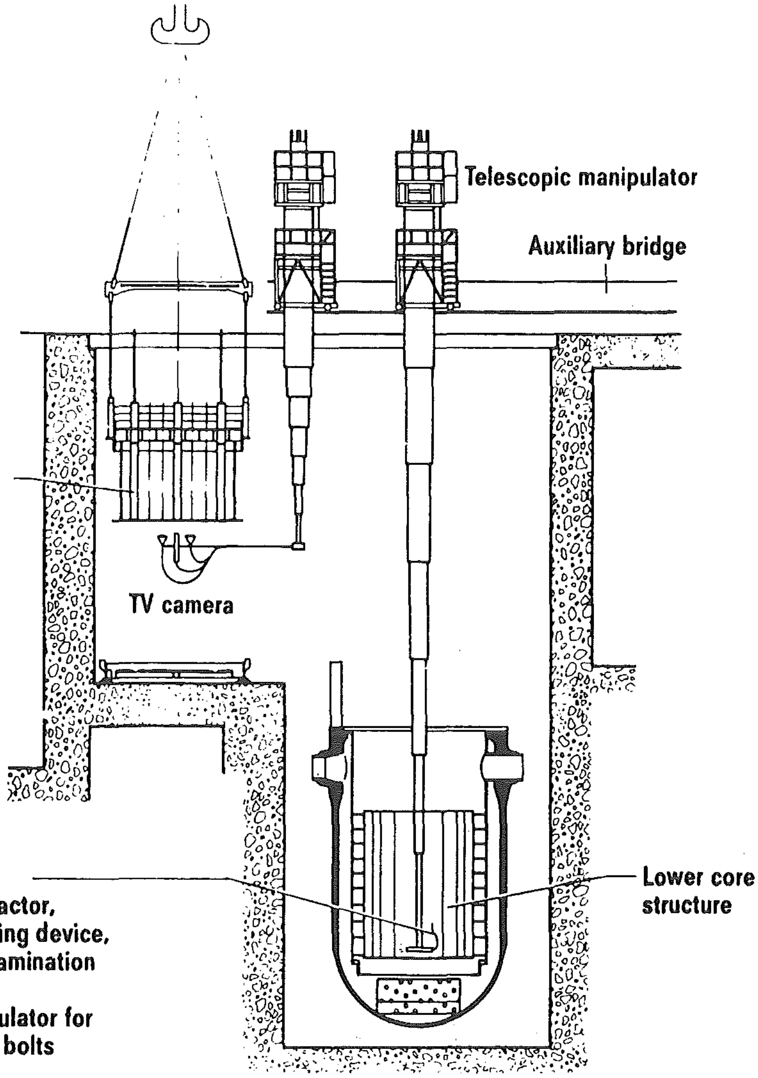
Fig. 10

Permanent Fixtures for Inservice Inspections of the Reactor Coolant Pressure Boundary (excluding RPV)

E 84 153 e

Fig. 11a

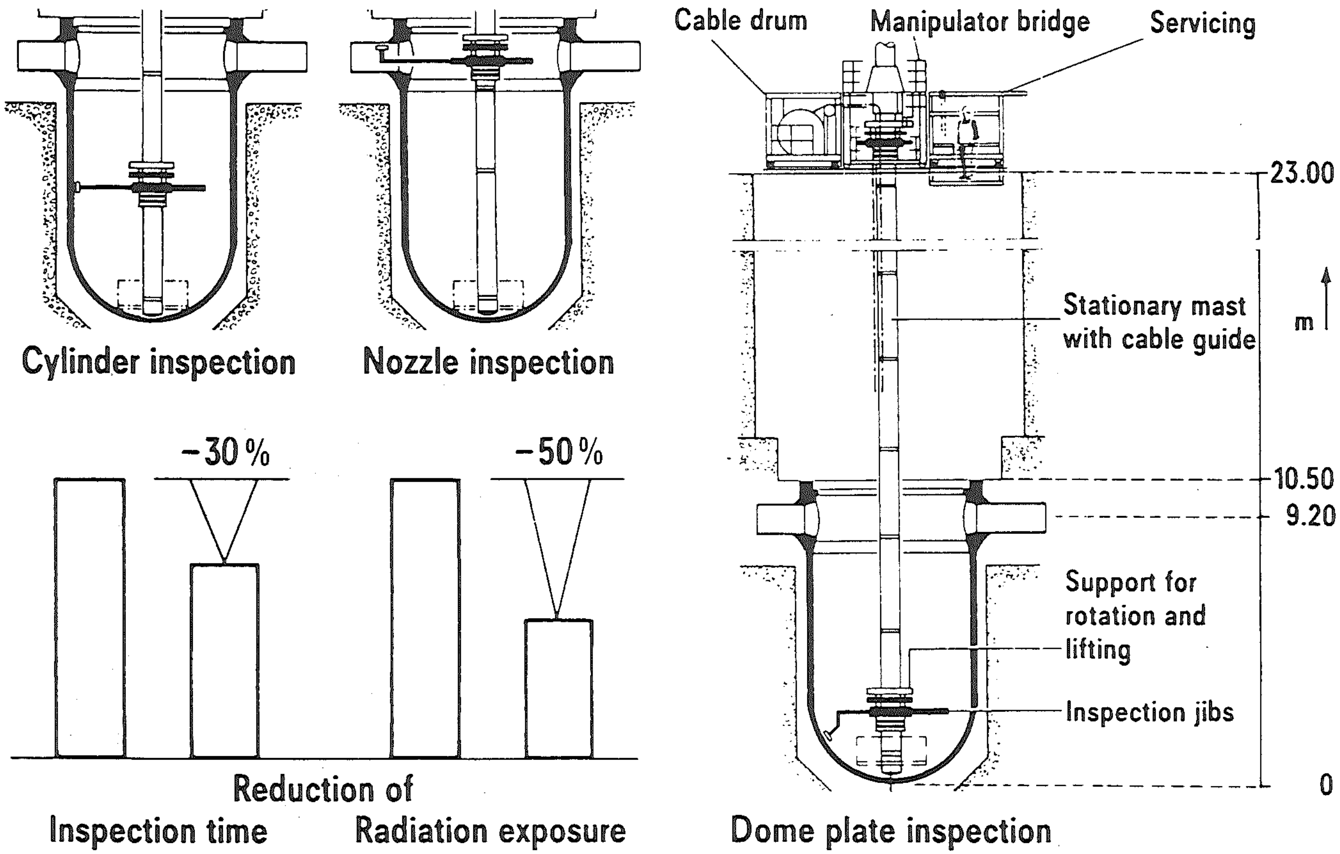
KWU



Servicing of RPV Internals with the Aid of a Telescopic Manipulator

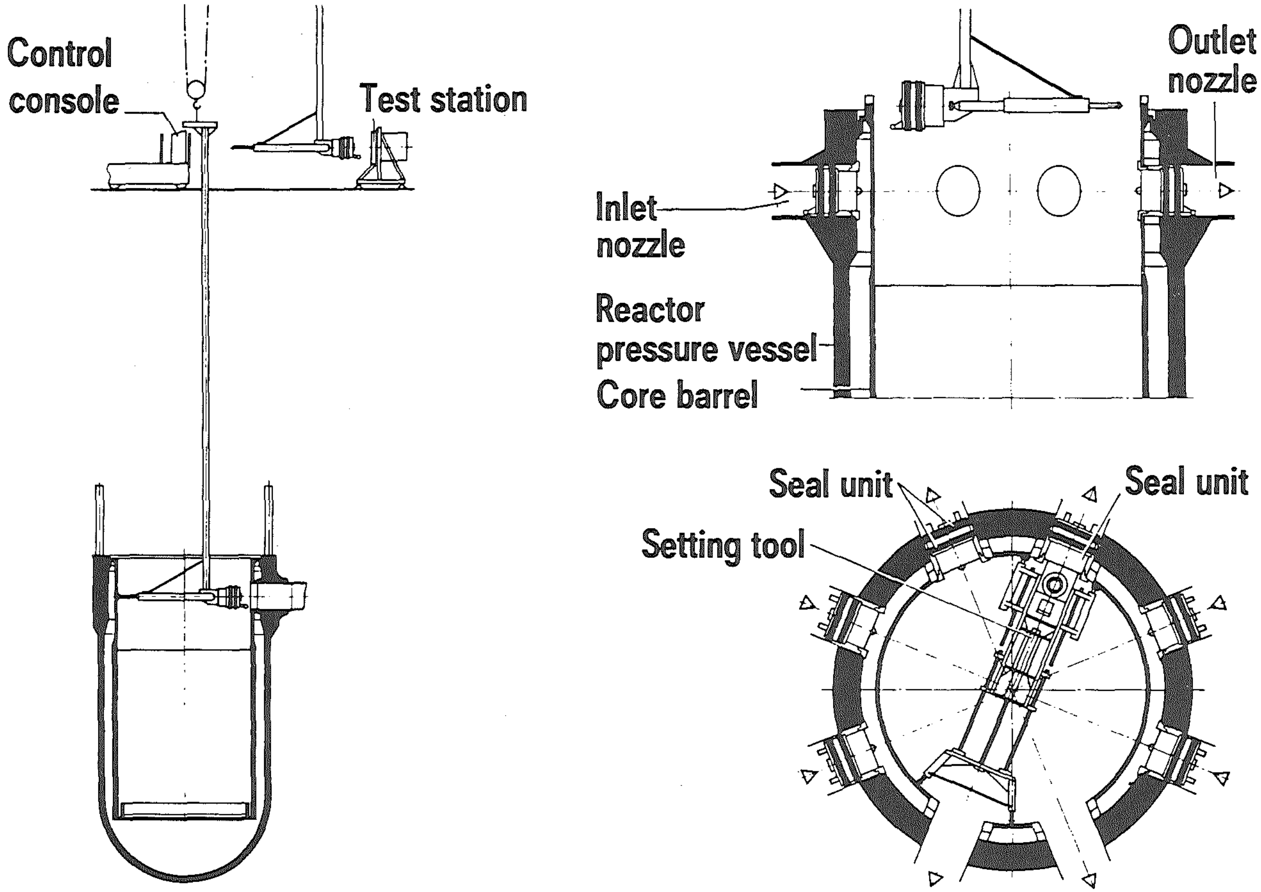
E 84 417 Ce

Fig. 11b



PWR, Extension of Plant Life –
Remote Controlled RPV – Inservice Inspection with New KWU – Manipulator

E84469 Ce



Sealing of RPV Loop

Fig. 11c

E 84 154 e

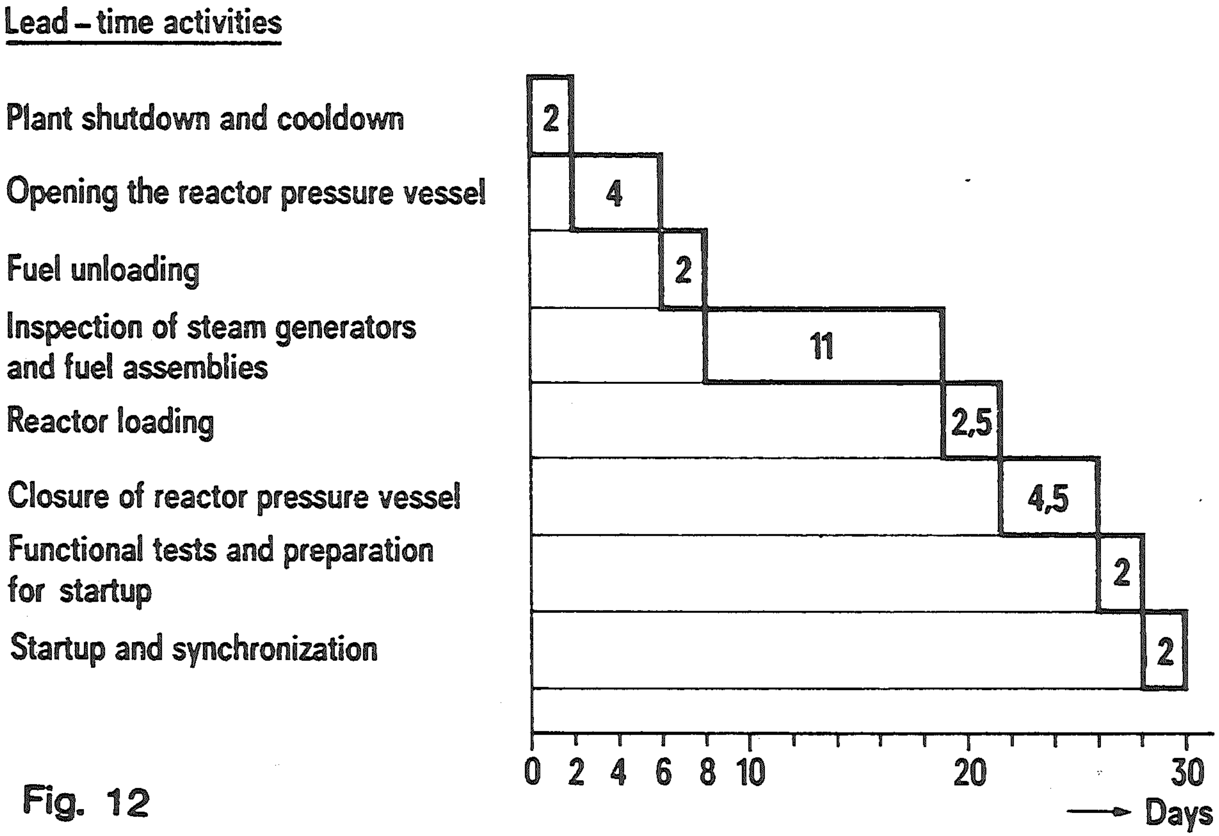
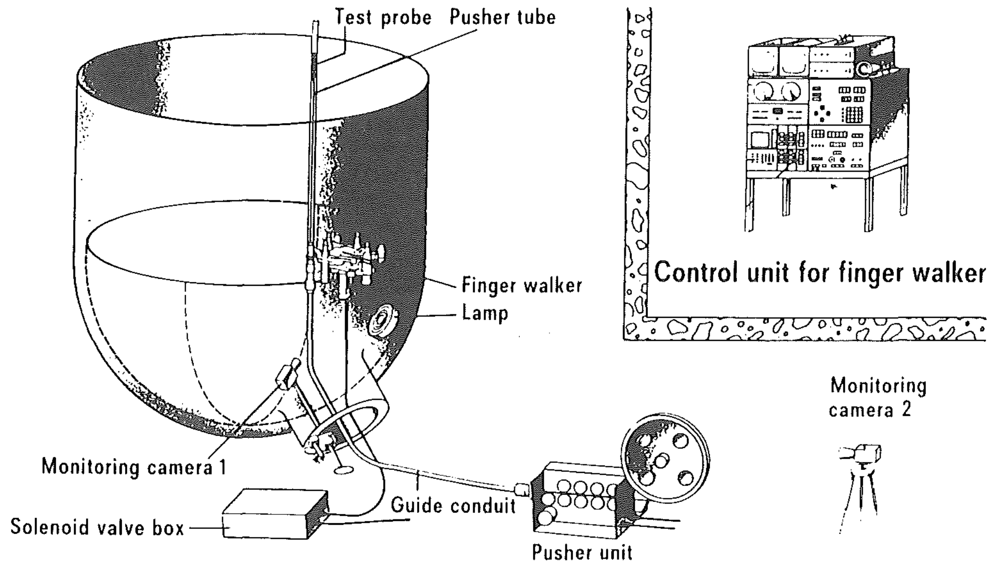


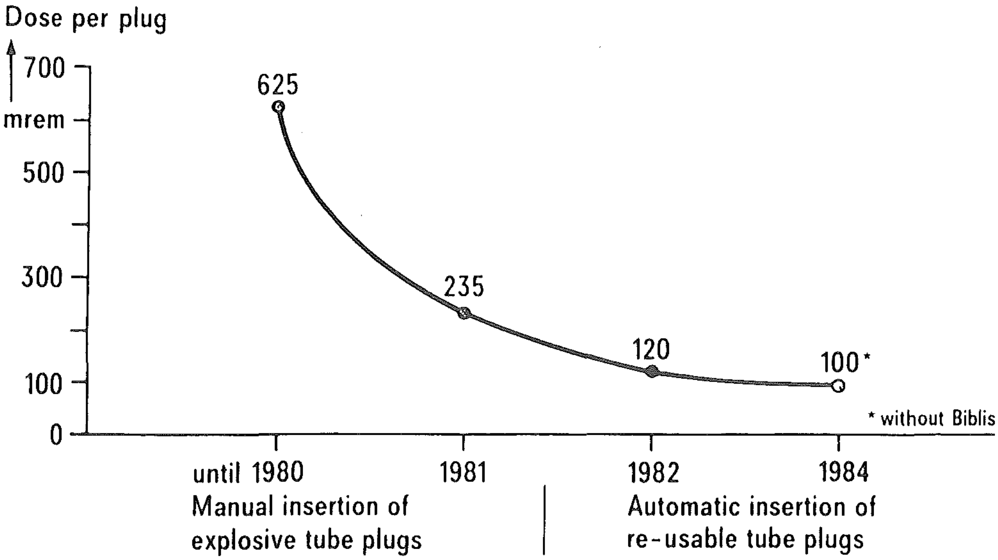
Fig. 12

1300 MW PWR Nuclear Power Plant
Time Schedule for Refueling and Major Inspection

E 84 151 e

Fig. 13 KWU

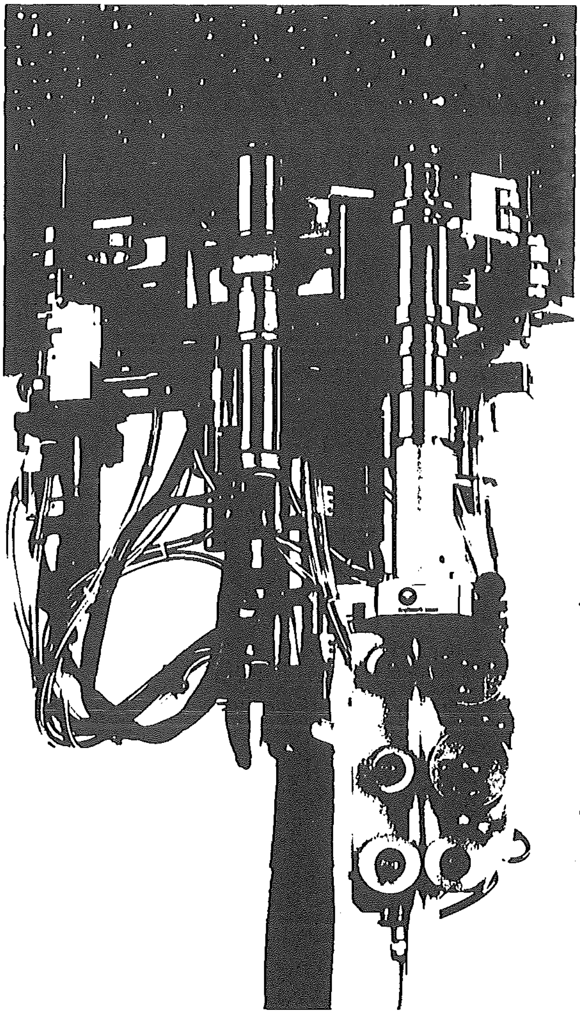




PWR, Extension of Plant Life – Remote Controlled Steam Generator Tube Plugging Results in Dose Reduction

E 84 460 Ce a

Fig. 14



Finger Walker Application

Tube testing e.g.

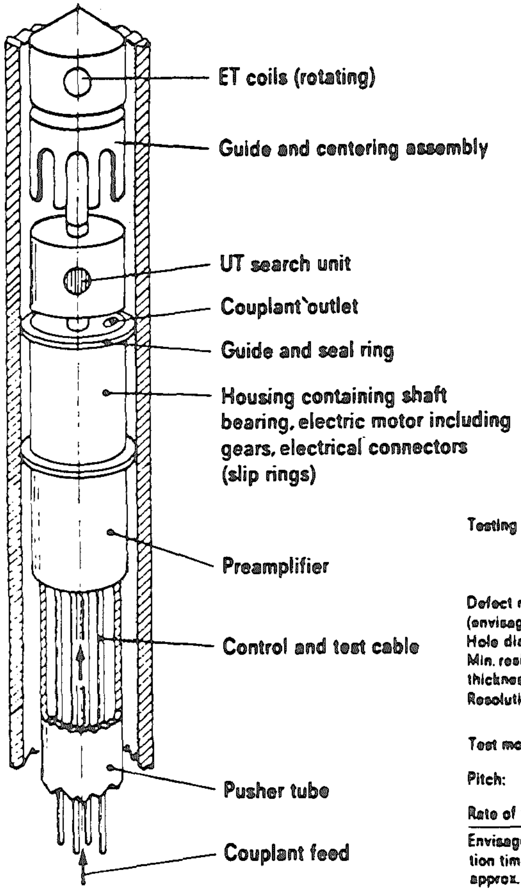
- Analysis and/or visual examination
- Eddy current testing

Tube repair e.g.

- Removal of weld material
- Setting of tube plug

PWR, Extension of Plant Life – Remote Controlled Steam Generator Tube Testing Using a Flexible Endoscope

E 84 459 Ce

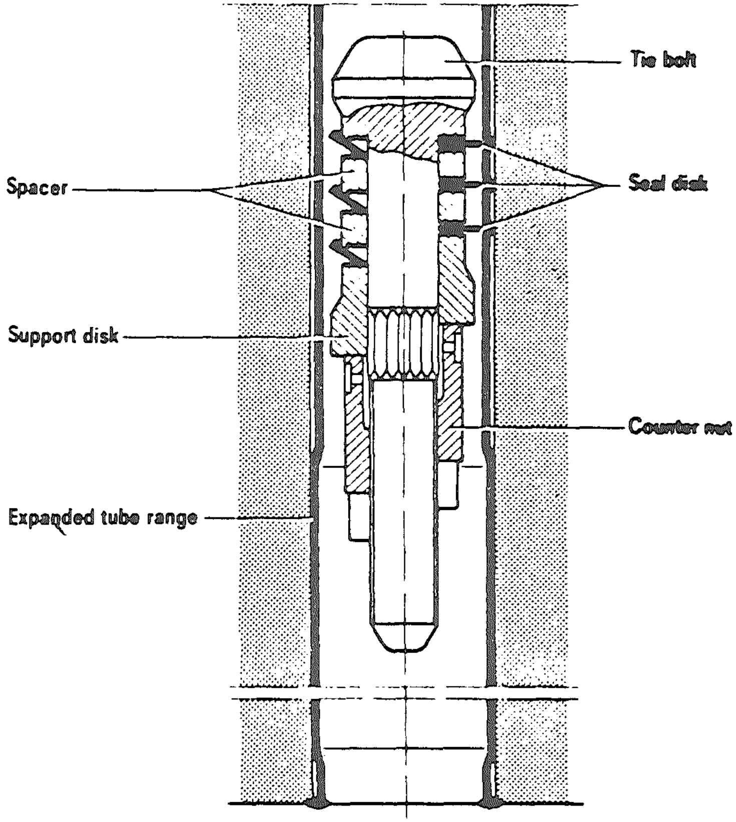


Testing range:	500 mm above the tube-sheet to the center of upper roller expanded area	
Defect resolution: (envisaged)	UT	ET
Hole dia:	2 mm	0,5
Min. residual wall thickness:	20 %	20 %
Resolution (depth):	±2,5%	<5 %
Test motion:	helical	
Pitch:	⩽2 mm	
Rate of travel:	10 mm/s	
Envisaged examination time: approx. 15 min		

Steam Generator Tube Examination
Analysis by means of Combined UT/ET Rotating Probe

Fig. 15a

E 83 305 e

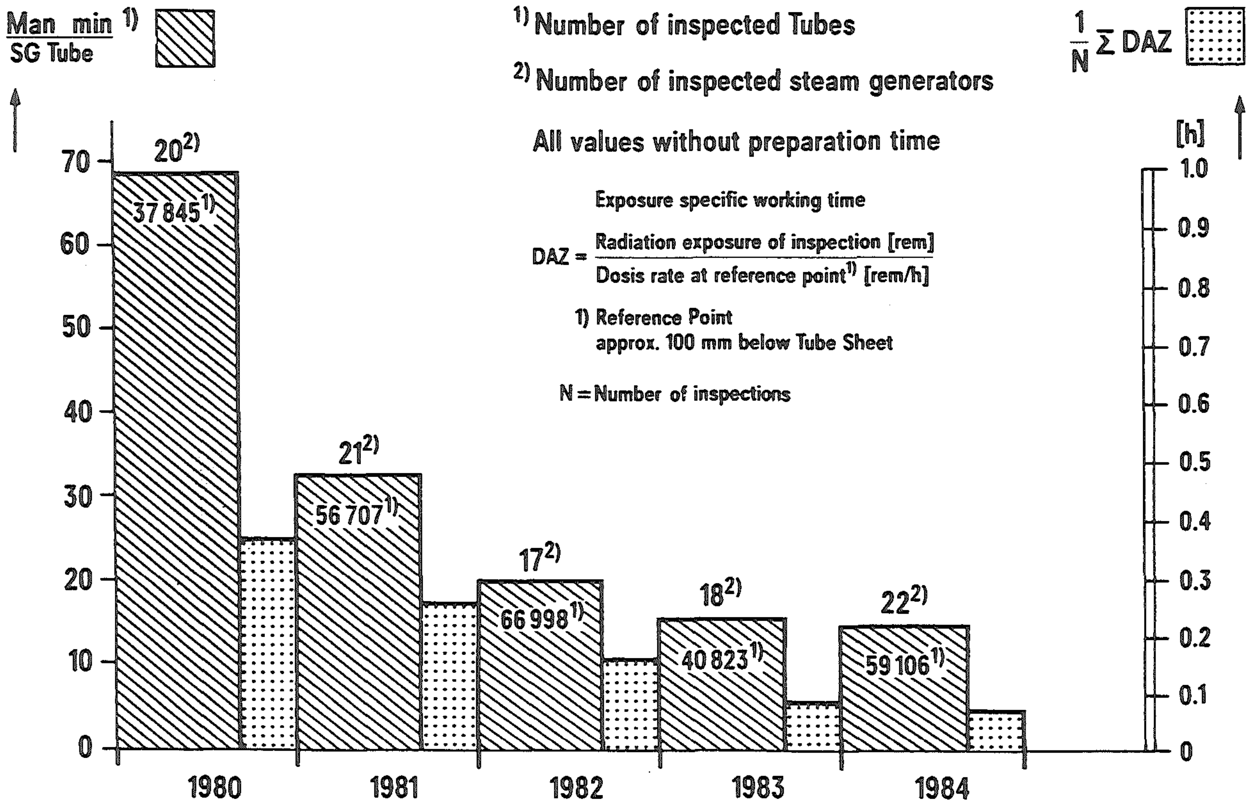


Mechanical Plug for Steam Generator Tubes

Fig. 15b

E 83 320 e

Fig. 16

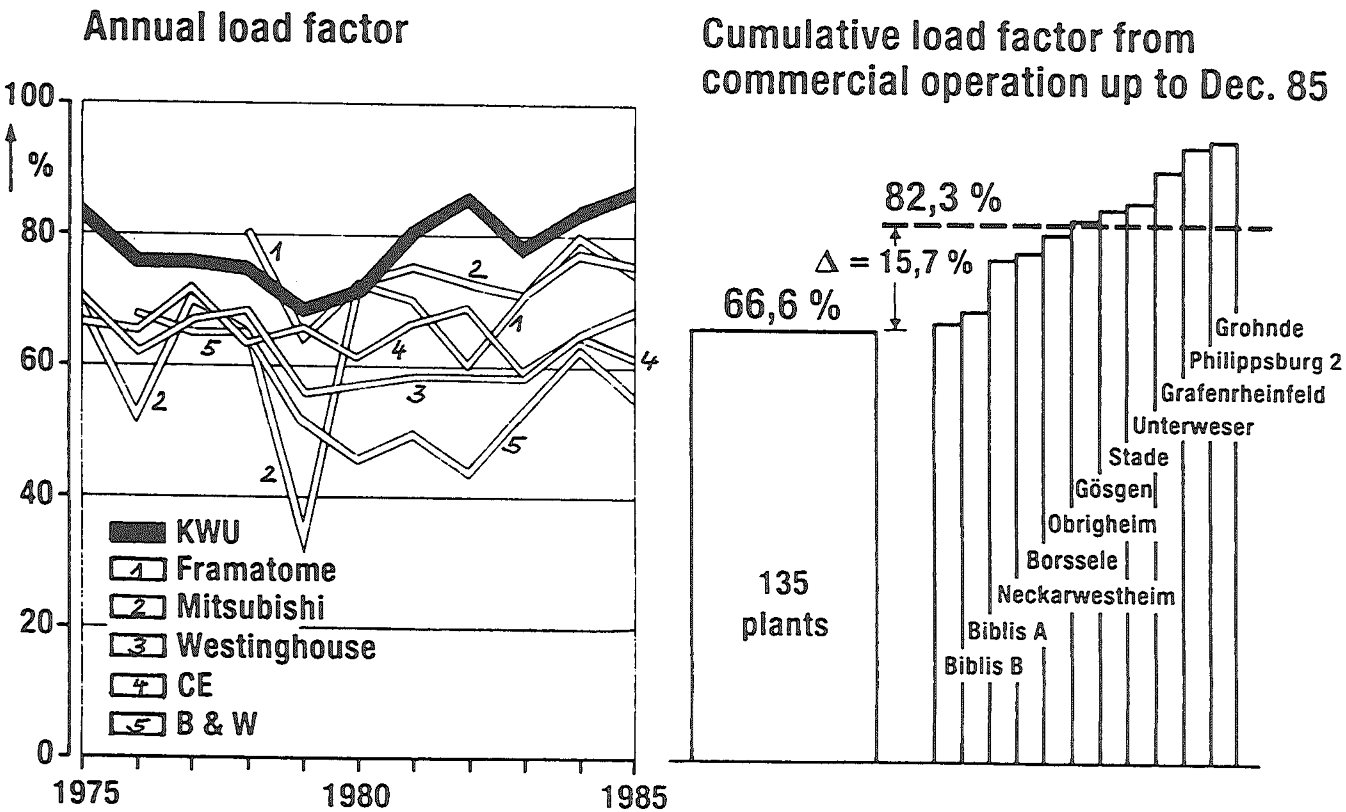


Review of Eddy-Current Inspection on Steam Generator Tubes

Refering to Number of Inspected Tubes, Dose-and Time Reduction

E 85 056 e

Fig. 17



PWR Nuclear Power Plants in the Western World
Annual and Cumulative Load Factor up to December 1985

86 342 Ce

Gesellschaft für Reaktorsicherheit (GRS) mbH

PROBABILISTIC RISK ANALYSIS FOR NUCLEAR POWER PLANTS

Ulrich Hauptmanns

Lecture held at the German - Indonesian Seminar on Public Acceptance, Waste Management, and Nuclear Safety
Jakarta, October 7-9, 1986

Schwertnergasse 1 · 5000 Köln 1 · Telefon (0221) 2068–0 · Teletex 2214123 grs d

1. INTRODUCTION

My talk is on probabilistic risk analysis or, as it is frequently called, risk assessment. The latter term indicates that a good deal of engineering judgement is required to perform such an investigation and that it is by no means entirely a "first principle exercise", as will become clear in the course of my exposition. Risk is understood to be composed of two elements: the expected frequency of an undesired event and the magnitude of damages it causes. In the analysis of a nuclear reactor it is the expected frequency of a major release of radioactive substances on one hand and the extent of this release and the consequent impact on humans and environment on the other.

Risk analysis is applied if the calculation of risk from observed failures is not possible, because events contributing substantially to risk are too seldom, as in the case of nuclear reactors. The process of analysis provides a number of benefits. Some of them are listed in Figure 1.

After this by no means complete enumeration of possible benefits to be derived from a risk analysis I should like to give an outline of risk studies for pressurized water reactors with some comments on the models used. The presentation is indebted to the detailed treatment of the subject given in the PRA Procedures Guide /1/. Thereafter I shall communicate some results of the German Risk Study, Phase B, which is under way. My talk concludes with some remarks on probabilistic considerations in licensing procedures.

2. OUTLINE OF A RISK ANALYSIS

2.1 Generalities

The steps involved in a risk analysis are shown in Figure 2.

They comprise analyses of

- the technical systems of the reactor
- the containment

Improved understanding of the full range of accident sequences and assessment of their relative importance

Assessment of the efficiency of planned system improvements and mitigating measures

Establishment of research priorities on the basis of the impact of gaps of knowledge on the final result

Explicit indication of uncertainties involved in the analysis

Figure 1: Some of the benefits to be derived from a probabilistic risk analysis

- the environmental transport of pollutants and the assessment of their health and other effects

The investigations require the modeling of phenomena from the fields of reactor physics, thermal-hydraulics, structural mechanics, atmospheric dispersion, health physics. Accident progression has to be described by means of event trees and fault trees for the plant systems. Evidently the analysis is a multidisciplinary exercise.

Owing to the multiple barriers present in a nuclear reactor a major release of radioactive substances to the environment is only possible, if the reactor core melts and the pressure vessel and the containment of the reactor fail. A situation leading to core degradation or core melt may only arise as a consequence of loss of coolant from the primary system piping or due to transients if in addition a number of highly reliable safety systems fail. Transients imply that there is either an increase of heat production in the core or a drop in heat removal without coolant being lost.

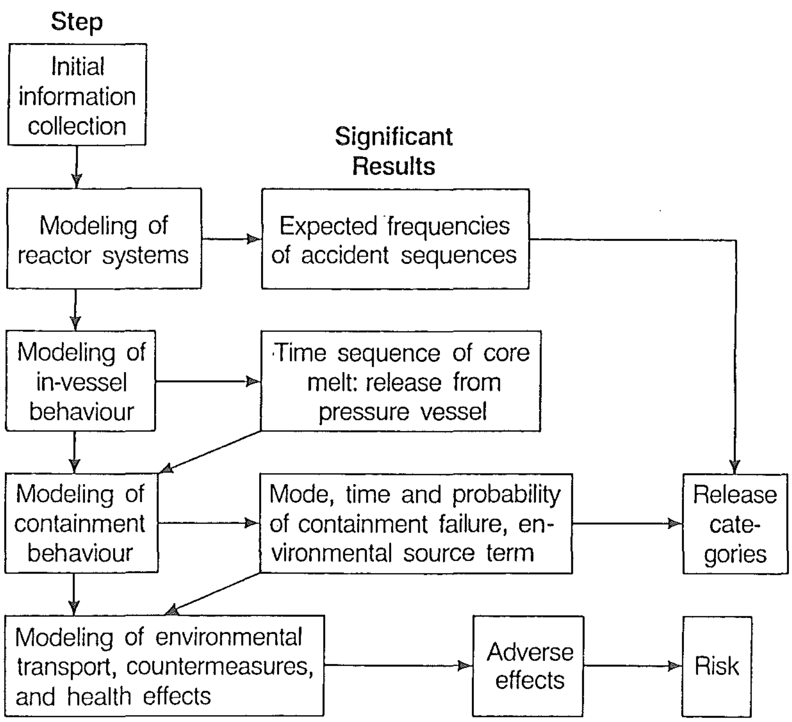


Figure 2: Probabilistic risk analysis - overview

2.2 Initiating Events

The first event in the chain of events which may lead to core degradation or core melt is called initiating event. Those analyzed in the German Risk Study Phase A /2/ are shown in Figure 3.

Loss of coolant

Leaks in the primary piping system
Leak in the pressurizer system
Leak in the reactor pressure vessel
Leak from a connecting line to the primary piping system

Transients

Loss of power
Loss of the main feedwater supply
Turbine trip with loss of heat sink
Anticipated transients without scram

Figure 3: Initiating events from /2/

The initiating events presented in Figure 3 represent the principal of the so called internal events. In order to be complete, external events would have to be added to the list, e.g.:

- earthquakes
- high winds and lightning
- floods
- low water
- aircraft crash
- pressure wave from an explosion

These may affect plant systems as well.

The expected frequencies of occurrence of the initiating events are obtained from statistical records, from fault tree analyses, from structural mechanics calculations in the case of leaks or from estimates. Only if a number of safety systems fail an initiating event may lead to core degradation or core melt.

The behaviour of these systems is analyzed in the task of system modeling.

2.3 System modeling

System models describe the behaviour of plant systems in response to initiating events. If plant systems are capable of coping with an initiating event the accident sequence will be terminated successfully. If this is not the case core degradation or core melt may result. Figure 4 gives an overview of this step of analysis.

Modeling of Reactor Systems

Methods	Data requirements
Event tree analysis	Expected frequencies of initiating events
Fault tree analysis	Reliability data for independent and dependent failures; probabilities of human error
Neutronic and thermal hydraulic calculations to establish sucess criteria	Nuclear and thermal-hydraulic design parameters

Output: Accident sequences leading to core melt due to loss-of-coolant and transients and expected frequencies of occurrence

Figure 4: Overview of reactor system modeling

The principal tools for modeling systems are event trees and fault trees. An event tree is the result of an inductive analysis which describes the behaviour of all the systems required to cope with an initiating event. Normally it is a binary model, i.e. a system whose functioning is required either fulfills its mission or does not do so. Figure 5 gives an example in which for ease of presentation several safety systems have been combined into one. Each of them only fails if several of its components fail. If the systems are well constructed and a sufficient number of them with the necessary functions are installed the reactor copes with the initiating event. The corresponding sequences represent the success paths of the event tree which are characterized by the fact that all systems which are required work as planned. If this is not the case in the example of Figure 5 a core melt will occur and, if containment integrity is not assured, a release may result. Since the ultimate aim of the analysis is quantification the probability of whether a system works or not is found using fault tree analysis. In this type of analysis the failure of a system to fulfill its mission is traced back deductively to the failure of its individual components. These components may either be technical components in the strict sense of the word or they may represent failures to carry out human interventions or - if external events analysis is included - the consequences of their impact on the system. The fault trees take into account the possibility that components of the system under analysis may have been damaged due to the failure of other systems or as a consequence of the initiating event.

The question of whether a system works or not or a component has to function or not for the system to fulfill its mission may only be represented by a binary yes/no variable if the dynamic behaviour of the system in response to the initiating event is known. The necessary knowledge is usually obtained by performing neutronic and thermal-hydraulic calculations. Their results are the basis of the so called success criteria. For example, a thermal-hydraulic calculation may show that no high pressure injection system is required to cope with a 20 cm^2 leak in the primary piping. This system will then not be considered in the corresponding event tree.

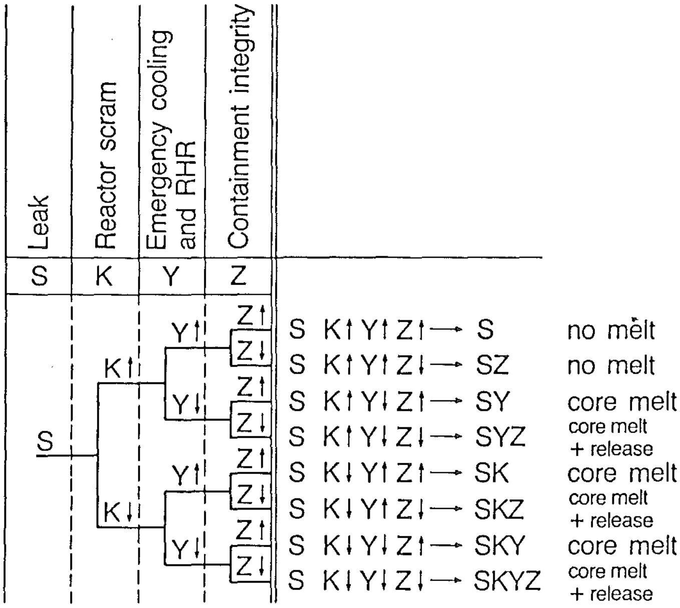


Figure 5: Simplified event tree for a loss-of-coolant-accident (from /2/)

A short cut which is frequently used in this context, e.g. in the German Risk Study Phase A /2/ and the U.S. Safety Study /3/, is to base success criteria on the conservative requirements laid down in the licensing procedure.

Well known computer codes for addressing questions of core cooling in the case of transients are the ALMOD code /4/ and for loss-of-coolant-accidents DRUFAN /5/. Other codes used in this context are RELAP /5/, RETRAN /6/ and TRAC /7/.

All the computer codes require input data. For evaluating fault trees reliability data describing the failure of technical components and probabilities for human error are needed. Reliability data are best obtained by observing failures of components in operation in power plants /9/, the evaluation of human error is performed by an analysis of the tasks, which are broken down into simpler tasks for which observed error probabilities are available /10/. The neutronic calculations require amongst others information about core geometry and composition, neutron cross sections and reactor power, the thermal-hydraulic ones, the thermodynamic and hydraulic parameters of the system, material inventories, heat capacities and heat transfer correlations.

By their very nature the models used in an analysis are an abstraction from reality. Therefore their representativeness must be a concern. For example, it is impossible to make the list of initiating events complete. Owing to the large number of analyses performed to date and the existing operating experience it is believed, however, that omissions of accident sequences which would substantially alter or negate insights from probabilistic risk analyses are unlikely /11/.

Thermal-hydraulic calculations will draw benefits from experiments which are under way and from improvements in analytical models.

Reliability data for independent failures are now available in sufficient quality and number for pressurized water reactors of German design /9/. However, information on common mode failures is still considered to be a problem. The same is true for the treatment of human error which naturally is more complicated than the description of technical components. In this field principally the failure of carrying out properly maintenance and planned interventions during operation are treated analytically. Unforeseen acts and interventions apt to control complex situations are still difficult to model.

In general the state of knowledge in the step of analysis just described is considered as good. Further improvements may be expected from the evaluations of operating experience which are carried out in many places.

3. SEVERE ACCIDENTS

This step deals with event sequences which are described by the failure paths of the event trees just mentioned. These are characterized by the fact that the safety systems are not capable of coping with the initiating event. The resulting accidents go beyond the design basis accidents. They are called severe accidents and lead to core damage or core melt. Results of risk studies indicate that they are very unlikely.

3.1 In-Vessel Behaviour

After the expected frequencies for the different accident sequences have been established, the actual progression of core melt has to be treated analytically to predict the temperature history of the fuel. In addition the quantity and form of release from the fuel during heat-up have to be found. An overview of this step of the analysis is given in Figure 6.

Normally in-vessel behaviour is not treated for all the accident sequences found in the previous step but only a few cases are selected. In what follows the phenomenology to be modeled is explained using the uncoped loss-of-coolant accident as an example.

3.1.1 Core Melt

With the drop of the water level in the core region the fuel heats up. The rate of heating is determined by the decay heat level, zirconium oxidation at high temperatures, convective heat transfer to steam and hydrogen and radiative heat transfer to structures.

As the fuel heats, cladding swelling and rupture occur. With a further rise in temperature zirconium, zirconium oxide and uranium dioxide will melt. The molten material is expected to slump and resolidify in the lower parts of the core causing some degree of flow blockage in the channels. Similarly control rods would melt. A molten zone is expected to grow and

In - Vessel Behaviour

Models/Phenomena	Input information (partial)
Calculation of heat transport between coolant and fuel, fuel heat-up and melt, heat production from metal/zirconium reaction	Number of fuel rods, initial power and water levels, geometric and caloric characteristics of core, heat transfer coefficients etc.
Calculation of isotope generation and depletion due to fission, transmutation and decay	Nuclear cross sections, decay rates, fission yield, fuel mass and burn-up
Correlations for fission product and structural materials from fuel by cladding rupture, diffusion, leach and melt	Geometric data of fuel elements, gap inventory, rod inventory, temperatures at release location, release rate coefficients
Correlations for transport inside cooling system describing processes like reactions of products with each other or with air or steam, hydrogen, sorption, settling, re-evaporation and re-entrainment	Physical properties of radionuclides, geometric configuration of reactor coolant system, materials of surfaces, source term from the core, flow path through and thermalhydraulic conditions in cooling system
Characteristic results:	Time sequence of core melt, pressure vessel melt through, source term to the containment

Figure 6: Overview of modeling of in-vessel behaviour

to progress downward following the receding water level. It eventually enters the lower plenum of the pressure vessel.

When molten fuel in the lower plenum comes into contact with the water present there, an interaction will occur. The fuel is dispersed and steam is generated. Under some conditions, a particularly energetic reaction, known as "steam explosion" may be produced. It will be discussed in detail later. After the molten fuel has drained into the lower plenum, the remaining water boils away in a short time. Reactions of core debris with zirconium or steel would then occur producing more hydrogen and heat. The bottom of the vessel will be heated up and eventually yield. The contents of the vessel is then discharged into the reactor cavity. According to results obtained in phase A of the German Risk Study this would take place after 1.6 or 2.2 h, respectively, depending on the boundary conditions used for the calculations /2/.

The phenomena just described may be treated with the MARCH code /12/ which despite improvements on a previous code remains a very simple model for the complex processes involved.

3.1.2 Nuclear core inventory

In parallel with the fuel heat-up release of radioactive materials from the fuel elements takes place. In order to calculate its quantities, in the first place the inventory of radionuclides and structural materials of the reactor has to be obtained. This includes radionuclides, fuel, stable isotopes produced by the decay of radionuclides during reactor operation, and structural materials like fuel cladding, control rods, core support, and instrument tubes. The radionuclide and stable nuclide inventories are determined with an isotope generation and depletion code. These codes like ORIGEN /13/ and its improved version ORIGEN-2 /14/ account for fission, transmutation, and decay. As input information they require nuclear cross sections, decay rates and fission yields, information on the initial nuclide inventory, uranium enrichment, and fuel element burn-up, and details on the quantities of structural materials present in the core.

3.1.3 Radionuclide and structural materials source term from the core

Releases of radionuclides from the fuel are expected to depend on the chemistry of the radionuclides within the fuel (kinetics and thermodynamics), the physical form of the fuel (e.g. cladding intact or failed, fuel solid or molten, fuel surface-to volume ratio) and the environment to which the fuel is exposed (e.g. temperature, fluid composition, and steam /water/ hydrogen ratio). Releases can occur in a variety of ways. The following phenomena have to be modeled:

- ° cladding-rupture release (T < 1200 °C)
- ° diffusion release
- ° leach release
- ° melt release
- ° transport, deposition, and release in the reactor coolant system

The aforementioned processes with the exception of the transport inside the coolant system, are treated by models based on correlations describing experimental results. Substantial uncertainties still present in this phase may be dealt with by assuming conservatively that the entire inventory of the primary system is eventually released to the containment. This is done in the German risk study, Phase B. It should be noted, that the major contribution to the radioactive source term to the containment results from the failure of the pressure vessel. This source term consists chiefly of aerosols with a great variety of particle sizes and iodine and noble gases.

Improved accuracy of the models required for this step may be expected from a number of experiments, as for example the SASCHA experiment conducted recently at the Karlsruhe research centre /15/.

3.2 CONTAINMENT FAILURE AND IN-CONTAINMENT BEHAVIOUR OF FISSION PRODUCTS

This step is concerned with the different modes of containment failure and the description of the behaviour of the molten fuel within the containment. The object is to calculate the release to the atmosphere, the environmental source term. An overview of the methods and phenomena involved is given in Figure 7.

Containment failure and In-Containment behaviour of fission products

Models/Phenomena	Input (partial)
Containment failure:	
● Pressure build-up calculation and structural mechanics calculations for determining time of failure	State of plant before accident, pressures, temperatures, volumes, heat contents etc., physical properties of materials and fluids, geometry and size of components and internals, mass and energy fluxes into containment after accident. Containment material properties, location of welds
Treatment of fission product release from the core and transport and retention inside containment, determination of environmental source term	Containment source term, physical and chemical properties of released materials, containment and auxiliary building volumes and surfaces, filter efficiencies, reaction parameters, entrainmentment factors

Characteristic results: Quantities, composition, time, duration, height and energy release for different release categories

Figure 7: Methods and phenomena to be modeled for describing containment failure and in-containment behaviour

The containment may fail at an early stage of the accident, as would be the case if a hydrogen explosion occurred. The reason for this would be a pressure peak or generated missiles. Another way of early failure would be the failure to isolate containment penetrations. Late failure of the containment would occur due to gradual pressure build-up as a consequence of evaporation from the water/core debris mixture which has dropped into the reactor cavity after penetrating the pressure vessel.

In phase A of the German risk study /2/, for example, the following failure modes of the containment were taken into account:

- failure due to steam explosion

- leakage from the containment, i.e. failures to isolate penetrations

  ° small (diameter 25 mm)
  ° medium (diameter 80 mm)
  ° large (diameter 300 mm)

- failure due to pressure build-up.

The failure of isolating the penetrations is immediate. The corresponding probability of occurrence results from fault tree analysis for the containment isolation systems.

In the case of gradual pressure build up the time and space dependent pressure and temperature profiles in the containment have to be calculated. This may be done using the codes CONDRU /16/ or RALOC /17/. Some of the conditions and phenomena to be addressed in this context are:

- gas composition (steam, oxygen, combustible and inert gases)
- coefficients of condensing heat transfer to structures
- temperature profiles in structures
- the effects of cooling systems
- hydrogen combustion
- heat source redistribution
- flow into the annulus.

To assess the containment response to pressure build-up structural mechanics calculations are required which may be performed in detail and with a high degree of accuracy using finite element codes such as ADINA /18/. These calculations determine the load required to make the containment fail.

A possible melt through of the concrete basemat of the containment is considered to occur later than any of the other containment failure modes. For this reason ground release is normally not treated in risk studies.

As has been mentioned before, there are interactions between the core debris which falls into the reactor cavity and the structural concrete. These lead to the formation of steam and hydrogen, carbon monoxide and dioxide and a gradual destruction of the concrete. In case of a loss-of-coolant accident, water is expected to be present in the sump. This water floods the molten fuel after the concrete of the cavern has yielded and is evaporated by the residual heat of the fuel. This evaporation has a significant influence on containment pressure build up. This phase of the accident may be treated with computer codes like KAVERN /19/ and WECHSL /20/. Radioactive material - although in smaller quantities than on containment failure - is released continuously from the molten fuel in the cavern. It enters the atmosphere of the containment chiefly in the form of aerosols and to a lesser degree as gas.

During the transport in the containment multiple reaction, solution, and settling processes reduce the reactivity concentration in its atmosphere. On the other hand, reentrainment and resuspension is expected on containment failure due to overpressurization. Aerosol behaviour may be treated with the code NAUA /21/ and the distribution and reaction behaviour of iodine with the code IMPAIR /22/.

There still exist considerable uncertainties in the treatment of in-containment transport which stem from a lack in understanding and experience in accident processes and fission product behaviour associated with severe accidents. They refer to release mechanisms and to the chemical form in which some of the fission products present themselves.

4. RELEASE CATEGORIES

After sketching the phenomena treated and the procedures applied for calculating the environmental source term for a severe accident, it should be mentioned that the combination of the different accident sequences for different initiating events causing core melt with the different containment failure modes leads to a great number of sequences of events. In order to facilitate an expedient treatment these - about 100 in the German Risk Study, Phase A /2/ - are grouped together to form the so called release categories where the release is characterized by

- similar quantities
- similar time and duration
- similar height
- similar energy liberation

The expected frequencies of each of the categories - 8 in the German Risk Study, Phase A /2/, are obtained summing the expected frequencies of occurrence of all the event sequences belonging to them. The release catagories represent the source term to the environment.

5. ENVIRONMENTAL TRANSPORT AND CONSEQUNCE ANALYSIS

Based on the environmental source term the transport of radioactive substances in the environment is calculated with the object of finding the consequences. Depending on the scope of the study these may include early fatalities and injuries, latent cancer fatalities, genetic effects, land contamination, and economic impacts. The results are usually presented in terms of complementary cumulative distribution functions, i.e. distributions which give the expected frequencies that the amount of damages exceeds a certain value.

Figure 8 gives an overview of this step of the analysis.

Environmental transport and consequence analysis

Models/Phenomena	Input (partial)
Atmospheric transport of radioactivity (mostly Gaussian dispersion)	Parameters describing release categories, weather data; e.g. wind speed and direction, rain frequency and intensity, stability classes
Countermeasure modeling (shelter, evacuation, decontamination)	Living habits, quality of housing, number of people in reactor vicinity
Exposition modeling: airborne exposition (cloud shine, inhalation), exposition from the ground (ground shine) and by ingestion with food stuffs dose effect relationships	Airborne radioactive concentrations and contamination of ground and plants, transfer factors for uptake in plants, enrichment factors in food chain, consumption habits, population distribution

Characteristic results: Airborne and ground concentrations of radioactive isotopes as a function of time and distance, acute and late fatalities, genetic effects (individual and collective)

Figure 8: Overview of consequence modeling

Most consequence-modeling codes simulate the atmospheric dispersion of the released material by using a Gaussian dispersion model to calculate instantaneous and time integrated ground - level and airborne concentrations and deposited levels of radioactivity. They take into account changes in atmospheric stability, wind speed, and precipitation mostly for each successive hour of travel time. In addition, the following effects are usually modeled:

- buoyancy of the activity plume due to thermal energy
- dilution in the wake of buildings
- radioactive decay
- dry and wet deposition

Among the possible countermeasures which are usually taken into account figure:

- seeking shelter in buildings
- evacuation and relocation
- decontamination
- restrictions of the consumption of agricultural products.

The effects on human beings are caused via several exposition pathways. Airborne radioactive material leads to radiation doses caused by external radiation from the plume (cloud shine) and radiation from inhaled radionuclides. In case of external radiation a model relates concentration in the air with doses delivered to various body organs (e.g. bone marrow, gastrointestinal tract). The radiation dose from inhaled radioactive materials is proportional to the airborne concentration of radionuclides at about 2 m height above ground. A metabolic model describes the behaviour of radionuclides in the body and serves in conjunction with a dosimetric model to derive the dose conversion factors which relate external concentration with potential health effects. Radioactive material deposited on the ground delivers radiation doses through three pathways: external radiation due to gamma rays emitted by deposited material (ground shine), the inhalation of resuspended radioactive material, and the ingestion of contaminated food and water. The ingestion of radioactive material may result from direct deposition on vegetation which is consumed by people or by animals serving as food or from the uptake of ground deposited radioactive material through the roots of plants.

After calculating the radiation-dose commitments, it is necessary to consider the health effects which may result. Whilst the dose-effect-relationship for high radiation levels which lead to acute effects if radiation is above a certain threshold is relatively well known, the corresponding relationship for low doses which produce latent effects is still object to discussion. Normally a linear extrapolation from high radiation levels is used to give probabilities for latent health effects. This procedure does not account for the existence of self healing effects which are believed to be present for low doses.

The procedure just outlined serves to calculate population risk if the population distribution around the plant is taken into account. Early effects are expected to occur only in the vicinity of the plant. In the case of latent effects a very large area may be affected.

The aforementioned calculations are usually performed using consequence modeling codes like CRAC /23/, CRAC-2 /24/ or UFOMOD /25/.

The capabilities for performing offsite consequence analyses are considered to be fairly mature. Yet uncertainties remain. They concern the effectiveness of the emergency response, the dry deposition rate of particulate matter from the plume, the modeling of wet deposition caused by rainfall and, as mentioned before, the dose-effect relationship.

6. UNCERTAINTIES

Uncertainties have been mentioned throughout my talk. They mostly concerned modeling uncertainties whose impact on the final results is difficult to assess. They are the consequence of insufficient knowledge about certain phenomena. They are not a drawback of probabilistic risk analyses, but should rather be considered as one of its advantages, since the analysis puts their existence into evidence. Other uncertainties concern input data.

Both types of uncertainties are described by subjective probability distributions and may be propagated through the calculations - although possibly at considerable expense of computing time. They are then reflected in the error band around the final result.

Some of the variables involved in the analysis are of stochastic nature, e.g. weather data. Their possible realizations are reflected by the cumulative complementary distribution function which describes the risk.

After this outline of a probabilistic risk analysis which despite its sketchy nature has become rather extensive given the considerable number of topics which have to be touched I should now like to turn to some results obtained in the German Risk Study Phase B which is underway.

7. SELECTED RESULTS FROM PHASE B OF THE GERMAN RISK STUDY

7.1 Generalities

Phase B of the German Risk Study was undertaken to increase the faith to be put into of results using improved models, methods of analysis and data bases. In particular, the effect of realistic minimum requirements for success criteria and results from the available operating experience were to be exploited. Subsequently the following points will be touched

- system and event tree analysis
- low pressure and high pressure core melt paths
- containment loads
- calculation of the environmental source term.

It should be kept in mind that work on phase B has not yet been completed and that the results I´ll quote represent only a small portion of the analyses to be performed in this context.

7.2 Systems and event tree analyses

Changes with respect to phase A /2/ in this step of the analysis principally result from:

- changes in the reference plant Biblis B since phase A was performed

- the use of minimum requirements for success criteria obtained from calculations with realistic boundary conditions

- the application of reliability data obtained from evaluating operating experience in Biblis B.

As a consequence of the results of the German Risk Study, Phase A /2/ a number of system modifications have been introduced in the reference plant, among them:

- partially automatic cooling down with 100 K/h (human interventions still necessary led to important contributions to core melt frequency in Phase A)

- improvement of the live steam relief system

- coolant pressure limitation for activating pressurizer relief

- closing of pressurizer relief if

  ° primary coolant pressure below a minimal value and relief valve open

  ° departure from nucleate boiling smaller than a minimal value

  ° containment isolation activated

  ° N16 signal is activated

- re-connection with the power grid in case of failure of the emergency Diesel generators

- reserve connection to the power grid

The calculations for loss-of-coolant accidents indicate that all leak sizes may be coped with by 1 high pressure and 1 low pressure system if cooling down of the secondary side of the reactor is started at latest 30 min after accident initiation. In Phase A /2/ success was only assumed if at least two high and two low pressure systems worked. In addition, the functioning of two or, at times more, accumulator systems was required.

In the light of operating experience the expected frequency of occurrence of small leaks in the primary piping system is considered lower by a factor of two as compared with Phase A. Fracture mechanics calculations indicate that the expected frequency of a guillotine break in the primary piping system including connecting lines is several orders of magnitude lower than the value of 2.7×10^{-4} a^{-1} used in Phase A /2/.

The effects of the aforementioned changes are shown in Figure 9 where the reliability data from Phase A are still used and changes may be expected with the use of Phase B data.

Initiating event	Expected frequencies of core melt in a^{-1}	
	Phase A	Phase B
Small leak in primary system piping	$5.7 \cdot 10^{-5}$	$6 \cdot 10^{-6}$
Power failure	$1.3 \cdot 10^{-5}$	$1 \cdot 10^{-7}$
Live steam line break	not analyzed	$2 \cdot 10^{-6}$

Figure 9: Contributions to core melt frequency for some initiating events (from /26/)

As can be seen there is a considerable reduction of expected core melt frequencies.

7.3 Low pressure and high pressure core melt paths

The phenomenology of core melt progression at low pressure after a loss-of-coolant accident has been described previously. An additional accident sequence analyzed in Phase B is core melt under system pressure. It results from an uncontrolled transient. The corresponding scenario implies that secondary heat removal is impossible for a long period of time.

In such a case coolant evaporates slowly and is discharged via the relief valves of the pressurizer. The primary system remains under high pressure and is heated up. When the water level inside the pressure vessel drops below the upper rim of the core, core melt begins. The pressure in the primary system is relieved only when after the melt of the fuel, about 3 hours after accident initiation, the pressure vessel yields. After pressure vessel failure high mass and energy fluxes from the primary system are introduced into the containment during a short lapse of time. This causes a pressure rise in the containment to values short of the design pressure. In the posterior phase pressure time history of low and high pressure core melt accident are similar, as can be seen from Figure 10.

Failure of the containment occurs in both cases after about 4 days. This should be compared with a failure after approximately 1 day which was obtained in Phase A /2/ for the low pressure path using less sophisticated modeling.

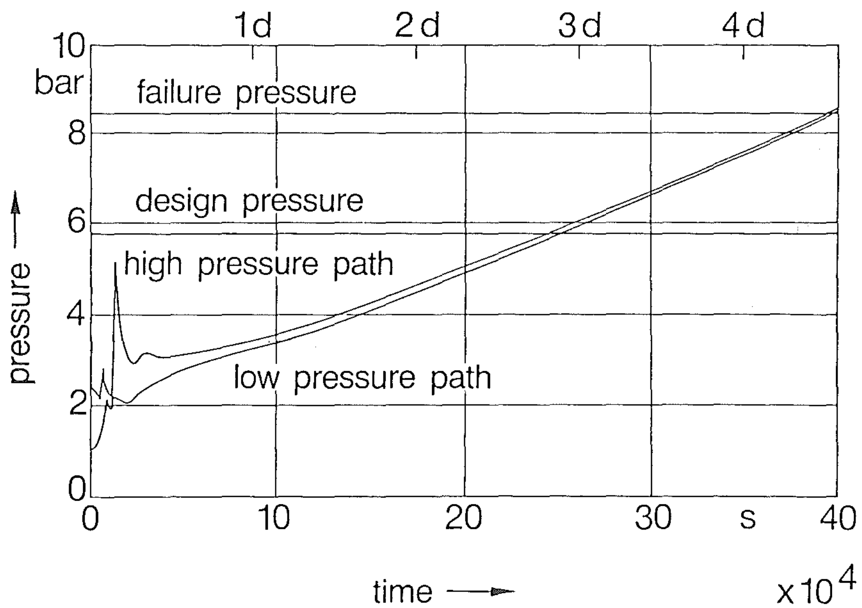


Figure 10: Pressure time history for the reactor containment in case of core melt

7.4 Loads on the containment

Some of the topics which have received special attention in Phase B of the German Risk Study are loads on the containment resulting from:

- a steam explosion in the reactor pressure vessel
- combustion from hydrogen in the containment

The violent evaporation of water on contact with highly dispersed molten fuel is called steam explosion. It might occur to a significant extent if considerable portions of the molten core dropped into water present at the bottom of the pressure vessel. Such a reaction might endanger the integrity of the reactor pressure vessel and subsequently that of the containment.

According to calculations performed with an extended version of the computer programme SEURBNUK /27/ masses up to 20 t of molten core material dropping into the lower plenum and reacting simultaneously do not produce dangerous loads for the pressure vessel. Since the fuel element bottom plates do not yield simultaneously, calculations show that at most 10 t of core material might be available for a simultaneous reaction with water. On these grounds a steam explosion with resulting containment failure is not considered to be an accident sequence of major importance /28/.

It is more difficult to assess the impact of a possible hydrogen explosion. There are two principal processes for producing hydrogen:

- the zircalloy fuel clads react with steam during core melt progression at about 950 °C

- in the core debris/concrete reaction steam is reduced to hydrogen by oxidizing substances from the core debris and concrete.

In case of the low pressure path it may be expected that until the moment of core debris contact with water from the containment sump about 1.300 kg of hydrogen have been released to the containment. It may not always be expected that hydrogen burns continously. Hence there exists a possibility of the formation of explosible mixtures. Figure 11 shows the pressure-time history for the low pressure core melt path.

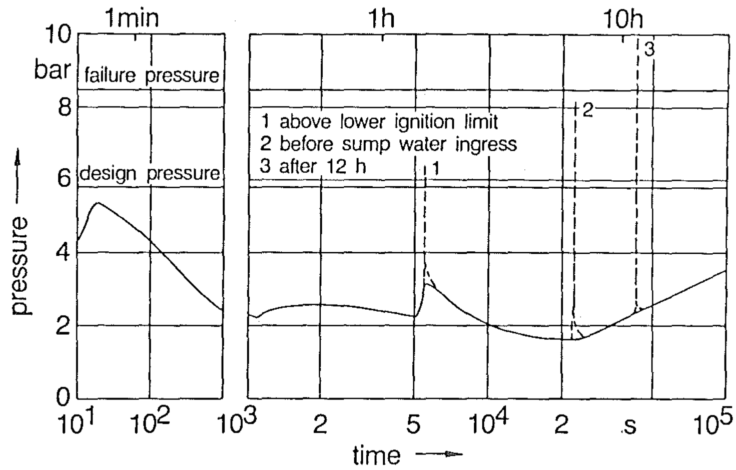


Figure 11: Pressure build-up in the containment resulting from H_2-combustion for the low pressure core melt path

The pressure peaks visible in the figure are due to a hydrogen combustion supposed to occur at different instances of time. If the mixture ignites on reaching the lower ignition limit, the peak is slightly above the design pressure. If ignition occurs at a very late stage when enrichment is greater, the peak may exceed the yield pressure of the containment.

These results are intermediate and show that with the present state of knowledge a hydrogen explosion endangering containment integrity cannot be excluded.

8.5 Release of fission products

As has been mentioned before, containment transport of fission products and their eventual release to the atmosphere is a very complex subject. After a core melt accident the containment contains a mixture of vapour, gases and aerosols in a concentration of about 20 g/m^3. Its total quantity in case of a low pressure core melt at the beginning of the core debris/concrete interaction amounts to about 3 t of which 95 % is not radioactive. The initial aerosol density is reduced in the vapour atmosphere chiefly by sedimentation and sorption processes. In four days time, for example, the concentration of airborne aerosols drops by 5 to 6 orders of magnitude. Noble gases and the gaseous part of the released iodine are of course not reduced in this way. Calculations indicate that only 1 % of the iodine inventory is present as gaseous elementary iodine whilst the remainder reacts to form compounds, chiefly with cesium. In addition silver iodide which is not soluble in water is formed with the silver of the control rods /28/.

As has been said before, about 4 - 5 days will pass until overpressure failure of the containment is to be expected. This leaves a margin of time for possible countermeasures. A controlled pressure relief of the containment is among those analyzed at present. It implies opening a containment penetration by remote control allowing a relief to the auxiliary building. This measure is apt to prevent an uncontrolled possible containment failure. The containment is vented after pressure has risen above the design pressure, which in the case of the high pressure core melt path occurs after about three days. The sump water is expected to have evaporated two days later. After that containment pressure gradually drops to atmospheric.

Till the moment of pressure relief release is only due to the design leakage of the containment and there is considerable retention of fission products in the annulus and the auxiliary building. Release after pressure relief has been calculated assuming conservatively that fission products are released unfiltered and close to the ground from the auxiliary building. Apart from the noble gases the dominating release fraction corresponds to elementary iodine. This is because after pressure relief there is a prolonged release of the elementary iodine from the containment atmosphere. At the same time I_2 present in the sump water enters the containment atmosphere in gaseous form. The important process of release of the cesium iodine dissolved in the sump is the entrainment of droplets by steam flow above the boiling water surface. The fractions of the core inventory released are shown in Figure 12 (left hand side).

In general the expected releases of iodine and cesium are about one order of magnitude lower according to the calculations of Phase B as compared with results from Phase A /2/.

Higher rates of release result from accident sequences without containment isolation. The worst case is the failure of an air duct inside the annulus owing to the pressure wave caused by primary system failure. The results for this case are given in Figure 12 (right hand side) as well.

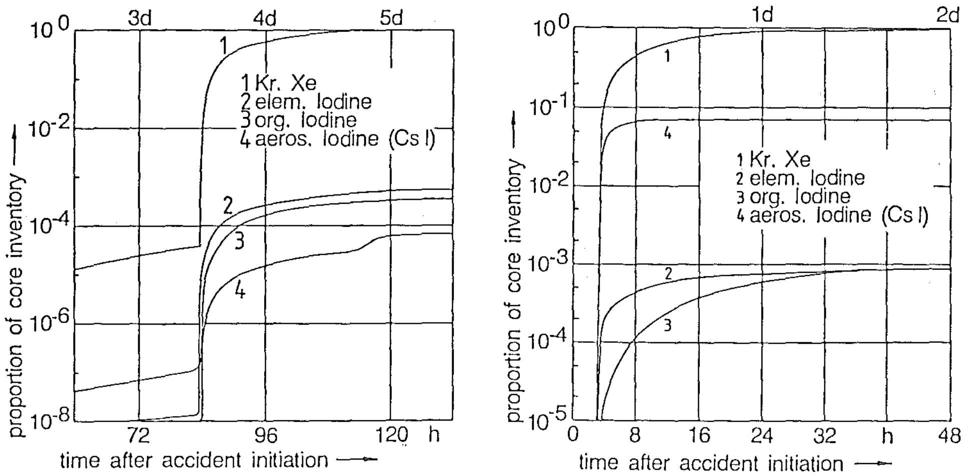


Figure 12: Fission product release in case of pressure relief from containment and air duct isolation failure

Results refer to the high pressure core melt path.

7.6 General appreciation

The work performed so far in phase B indicates that accident sequences leading to late releases are considerably more probable than those with early and therefore higher releases. In the case of a late release controlled relief of the containment is a possibility which would allow to contain the major part of radioactive material within the plant.

8. PROBABILISTIC CONSIDERATIONS IN LICENSING PROCEDURES

According to the German licensing procedure a nuclear power plant has to be capable of coping with a number of design basis accidents. These lead according to engineering judgement to maximum loads for the system and hence supply the boundary conditions for the design of safety systems. These systems have to fulfill in addition design principles like redundancy, diversity, geometric separation and the single failure criterion. This is essentially a deterministic approach, although, for example, the application of the single failure criterion or the decision on how redundant a system should be implies probabilistic considerations. However, no quantification is made.

The probabilistic analysis, on the other hand, permits an estimation of the probability with which the individual systems fulfill their mission and hence the probability with which an accident is coped with. This is an extension of the deterministic concept which implies that all systems work as planned, i.e. with a probability of 1. In this way a number of imaginable accident sequences are added to the success path. These arise from the failure of one or several of the safety systems. If the reactor systems are well constructed an accident progresses with a probability close to 1 along the success path whilst all other accident sequences are highly improbable. Probabilistic considerations supplement the deterministic procedure but cannot replace it. They answer the question to what extent existing safety systems are capable of coping with accidents other than the design basis accidents. In this way it is possible to analyze whether the design basis accidents have been selected correctly, i.e. in the sense of optimizing safety. Hence a probabilistic procedure permits to develop a balanced safety concept.

Whilst probabilistic investigations are used as supporting information for the licensing procedure in the Federal Republic of Germany, in the United States probabilistic safety goals stating requirements for individual risk are in use. The experience there seems to indicate that the safety goals should rather be interpreted as a general level of expected safety than as an acceptability criterion. This is due to the fact that a considerable margin of uncertainty is still associated with probabilistic risk analysis which would make the question of whether a result obtained in such a study meets the safety goals or not a debatable issue. This circumstance does, however, not invalidate the usefulness of probabilistic risk analyses for making recommendations concerning design features and operational requirements /11/.

In general probabilistic analyses may serve to throw light on the rationale behind deterministic licensing requirements and provide guidance for the future development of licensing procedures.

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J O I N T G E R M A N - I N D O N E S I A N S E M I N A R

ON REACTOR SAFETY

JAKARTA

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Major Reactor Accidents and Consequences

J. Wolters

Plenary Session

MAJOR REACTOR ACCIDENTS AND CONSEQUENCES

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1. INTRODUCTION

As far as the peaceful use of nuclear energy is concerned, it was true to state for more than 30 years that no person in the environment of a reactor plant was recognizably injured by a reactor accident. Since the Chernobyl catastrophe this statement can no longer be maintained. This does not mean that prior to Chernobyl no severe reactor accident happened. The contrary is true as we all are aware. But the quantity of radioactive substances released into the environment was always low enough to exclude health effects.

Nevertheless we have to remember that the development of fission reactor technology has not been free from severe accidents. Among them were a number which resulted in a partial or a total damage of the core and consequently in a release of large quantities of radioactive substances at least from the fuel. Since this is the condition for a major release of radioactive material into the environment accidents with core damage have been considered as major reactor accidents in this report irrespective of the actual environmental consequences. Some of these accidents happened in sodium-cooled (fast) reactors but they have not been included here since the report was confined to thermal reactors. In selecting major reactor accidents in thermal reactors no difference was made regarding the purpose of the respective reactor. In other words, military thermal reactors have also been taken into account.

2. REACTOR AND ACCIDENT DESCRIPTION

Table 1 gives a survey of the accidents and the reactors dealt with in this report. The accidents are listed in accordance with the sequence of their occurrence. They are subsequently also dealt with in this sequence.

2.1 NRX

The NRX was a Canadian research reactor situated in the research establishment at Chalk River. It had a thermal power of 30 MW, was moderated by heavy water and cooled by light water. Fig. 1 shows a vertical section through the reactor /1/.

The core resembled that of a Candu reactor with the exception that the so-called calandria stood upright. The calandria was a cylindrical aluminium tank with a flat bottom and top plate, which was vertically penetrated by equally distributed calandria tubes. The tank contained the liquid moderator and was surrounded by a solid reflector.

The 192 fuel rods made from metallic natural uranium and sheathed by an aluminium cladding were housed within the calandria tubes in aluminium pressure tubes, which penetrated the upper and lower shields and which were connected via headers to the main cooling circuit. The pressure tubes formed the coolant boundary within the reactor. The annular gap between the pressure tube and the calandria tube was filled with air which could be blown through in order to remove the residual heat during refuelling /2/.

The fuel elements were cooled by water from the Ottawa River, which after an appropriate delay was returned to the river. The coolant passed through the core in the downward direction and was thus heated up from 10 °C to 50 °C.

The accident happened on December 12, 1952 in connection with reactivity measurements /1/. For this purpose one fuel rod - it was a fresh one - was cooled by air and five were cooled by water fed in at the bottom of the pressure tubes and spilled into a gutter at the top. Certain other rods were connected to the cooling circuit by jumpers so that the flow was considerably less than normal. The reactor had not been up to power for several days /2/.

The accident was initiated by an unexpected supercriticality when the first control rod bank, the so-called safeguard bank, was brought up. The reason for the supercriticality was that three other control rods brought up by human error in advance had failed to drop in due to mechanical defects. Under these circumstances the safeguard bank should not have been brought out. But the interlock system which normaly would have prevented this was switched off. In addition, the reactor supervisor erroneously gave the order by a false characterization and the operator could not realize from the signals in the control room that it was a mistake /1/.

Due to supercriticality the reactor power rose to 100 kW within 20 s. At this time the operator tripped the reactor manually but only one of the four rods of the first bank dropped back into the reactor and that over a period of about 1.5 min. Thus the reactor power continued to rise. A tendency for the power to level off at about 20 MW was followed by a sudden increase of reactivity carrying the power to about 80 MW within 10 to 15 s. The rise in reactivity was caused by the onset of boiling of the light water in the pressure tubes with temporary cooling, the steam formation and the ejection of water from the core. In other words, the light water in this reactor had a positive void coefficient of reactivity due to the fact that the light water in such an arrangement with a different moderator mainly acts as a neutron absorber and simultaneously improves the resonance absorption in the uranium. The reactor became subcritical by dumping the moderator, by an inrush of light water at burst pressure tubes and by loss of uranium from the center of the reactor. For about 62 s the reactor power was beyond 1 MW.

22 fuel rods together with their pressure tubes were severely damaged, all but a few situated in the center of the reactor. Among them were 9 fuel rods, all iradiated, with normal cooling. The fuel rods with the special cooling, which lay in the flux maximum, suffered particularly extensive damage. In all cases central portions of the uranium and sheaths were disrupted and, with the exception of the air-cooled rod, the calandria tubes were punctur-

ed. That the latter only happened in the water-cooled positions is attributed to the fact that the chemical reaction between the molten metals, particularly uranium, and water played an important role. There were also strong indications that an oxyhydrogen explosion had occurred inside the moderator tank.

An intensely active cloud was discharged during the burst via the air cooling system, which maintained the pressure in the shield slightly below atmospheric, and via the stack into the atmosphere. A large burst of activity was also carried out to the river. But monitors at the first two water intakes down-river (14 and 23 miles) showed no increase of radioactivity above the natural level. The measured ground contamination downwind was nowhere very intense either. The reactor building itself was completely and highly contaminated. One very serious problem was the maintenance of fuel cooling since the heavily contaminated coolant could not be discharged in to the river and threatened to flood the basement of the reactor building. Ultimately 4500 m^3 water containing about $3 \cdot 10^{14}$ Bq of long-lived fission products was pumped into open trenches in a field 2 km from the site, which had been provided for the percolation of low-level radioactive waste water /1/.

2.2 Windscale I

The Windscale No. 1 reactor was one of two military reactors only used for the production of weapon plutonium. Both were commissioned in 1951. They were moderated by graphite and cooled by air. Fig. 2 shows a vertical section through the plant.

The reactor core consisted of a graphite pile with equally distributed horizontal channels for the accommodation of the fuel rods. The pile was a lying octogon with a height and breadth of 15 m and a depth of 7.6 m. It was housed in a concrete cavity. The fuel rod consisted of uranium-metal normally sheathed by aluminium. At the time of the accident the pile also contained fuel elements with a lithium-magnesium-alloy cladding. Loading and unloading of fuel elements was carried out from the charge hoist. Irradiated fuel rods were thus pushed through the channels to the discharge face where they fell into a water duct, via which they were transported to the reprocessing plant.

The coolant air was sucked through the pile by fans and was discharged into the atmosphere by a chimney of 130 m altitude and 13 m diameter /2/. The air entered the reactor at the charge face via latteral air ducts on both sides. Large air filters for the retention of radioactive aerosols were installed at the top of the chimney. The exit air analyzers downstream of the discharge face served to monitor the condition of the fuel cladding and to localize elements with defective cladding. Localization was carried out by a mobile scanning device.

The accident was initiated on the morning of October 8, 1957 and lasted about four days /3/. On October 7 the reactor was shut down to prepare the release of the so-called Wigner energy stored in the graphite due to the low operating temperatures. In the night of October 7-8 the core was heated up by nuclear power without air cooling to initiate the release of Wigner energy. A second nuclear heat-up followed several hours later when the reactor physicist had the impression that the temperatures of the graphite were falling again. He overlooked the fact that only a few values were falling whereas a number of values were

still rising. 15 minutes after the second nuclear heat-up the fuel temperature increased far more rapidly than was allowed. Therefore the reactor power was reduced instantaneously. Presumably one or more fuel claddings already became defective at this time.

In spite of the outage of the reactor the graphite temperatures rose with an increasing gradient and, on the evening of the October 9, one measuring point reached a value at which countermeasures had to be taken. By several periods of slight air cooling lasting 5 to 30 minutes the temperatures at all measuring points could be reduced with the exception of the peak temperature, which was only stabilized at the high value. The high level of radioactive substances in the exhaust air detected for the first time on the early morning of October 10 was at first dismissed as normal but later the correct conclusion was drawn that one or more fuel elements must have been damaged. The localization of the damaged fuel elements failed (sticking of the scanner) as well as the attempt to unload the channels with the highest fuel temperatures. At this operation it was discovered that the fuel rods were red-hot. By unloading the adjacent channels it was at least possible to prevent the fire from spreading. But it was not possible to reduce the temperature in the area concerned which covered about 150 channels on the evening of October 10. During the following night attemps were made to extinguish the fire by CO_2 without success. Only when water was used on the next morning could the fire be extinguished and the reactor be cooled-down. Melting of fuel obviously did not take place.

The committee charged with the analysis of the accident attributed the local overheating of the pile not to the sudden release of Wigner energy but to the oxidation of the fuel which was exposed to air by cladding defects. It is argued that the oxidation generated enough heat to finally ignite the graphite and the cladding material itself, which on the other hand exposed more metallic fuel to air.

During the accident large quantities of radioactive substances escaped into the atmosphere via the stack (Table 2) /4/. The dominant substance was iodine particularly iodine 131, which passed through the filters in the form of vapor. Other important nuclides like cesium 137, strontium 89 and strontium 90 were released from the fuel to a lesser extent and were largely retained in the filters.

2.3 SL-1 (Stationary Low Power)

The SL-1 was a test power plant situated in the National Reactor Testing Station of the USAEC in Idaho about 60 km from the town of Idaho Falls /5/. It was designed as the prototype of a small electricity power and heat plant for remote military bases. The plant was commissioned in 1958 and had a single circuit boiling water reactor with natural circulation as the heat source. It had an electricity output of 300 kW whereas the reactor itself generated a thermal power of 3 MW. All equipment of the plant, except for the control room, was accommodated in a cylindrical steel shell which was mainly designed as a shelter. Fig. 3 shows a vertical section of the lower central part of shell where the reactor was housed.

The cylindrical core (0.8 m diameter, 0.65 m height) of the SL-1 consisted of 40 fuel elements containing about 15 kg of highly enriched uranium in a UAL-meat, which was sheathed by a cladding of an aluminium alloy. The reactor was controlled by one central control absorber and 4 shim absorbers at the core edge. From the very beginning the shut-down reactivity was so small that the reactor core could reach criticality by the removal of the central cross-shaped control rod. For the balance of the excess reactivity necessary to meet the requirements for a long lifetime of the core, boron was used as burnable poison. The boron was contained in thin strips of aluminium alloy spot-welded to the fuel elements. Due to unexpected corrosion a relatively strong loss of boron was observed in autumn 1960 which was partly compensated by the insertion of cadmium strips into empty absorber positions in November 1960 /6/.

The core was housed in a slim pressure vessel of mild steel with an inner plating of stainless steel. Half of the pressure vessel was filled with water, which at the operating pressure of 20 bar adopted a saturation temperature of 216 °C. The core was immersed completely in the water. The space above the water level served as a steam accumulator.

The accident happened on January 3, 1961. At the time of the accident the reactor had been shut-down for 12 days for routine maintenance. The control room was unoccupied. Only the three members of the armed forces killed by the accident were present. They had received orders to reconnect the control rods to the drive mechanisms, which had been disconnected in order to open the reactor vessel. During this operation the central control rod was lifted far beyond the position at which the reactor became critical, as the later investigation revealed /7/. The cause could not be clarified but there were strong indications that the rod had become jammed. In this respect a lot of difficulties had been encountered during previous reactor operations.

The lifting of the central control rod resulted in a prompt supercriticality of the reactor accompanied by a power excursion to about 19,000 MW with a total energy generation of 130 MWs. The later analysis of the destruction revealed that the central part of the core had melted and partially vaporized. Additional energy of 24 MWs was produced by metal-water reaction. The sudden steam formation in the core produced an estimated pressure of 35 bar, which accelerated the water column beyond the core to a velocity of about 9 m/s. When the water impinged on the vessel lid it caused a 'water hammer' of about 700 bar. This force lifted the vessel by about 3 m, whereby the upper shielding was penetrated. The central control rod was ejected from the vessel but did not penetrate the reactor building. It fell back on the vessel.

In total 20 % of the core melted and released fission products, which could escape into the reactor building via the hole the ejected control rod had left. The radiation level inside the building reached a peak value of about 1000 R/h. It decreased with a half-life of about 40 days. Small quantities of gaseous fission products, mainly iodine, were able to escape from the building into the environment.

2.4 Lucens

The test power station at Lucens, Switzerland, was an exclusively Swiss development. It was installed underground in three artificial rock cavities of which one contained the reactor /8/. The 30 MW calandria type reactor was moderated by heavy water and cooled by carbon dioxide. Its design resembled that of the NRX.

One special feature of the reactor was the fuel assembly which formed a unit with the pressure tube, as is shown in Fig. 4. Pressure tube and fuel assembly were changed together by a handling machine acting from the room below the reactor. An adapter attached to the top side connected the unit to the cold and hot gas leg of the main circuit. The fuel assembly consisted of three slim graphite blocks held together by three tie rods and containing the fuel rods in one central and six peripheral channels. The fuel rods were made from uranium metal sheathed by a tube of magnesium alloy. The cladding was fitted with fins to improve the heat transfer to the gas.

The graphite blocks served as a baffle. The gas flowed downward in the outer annular gap, was reversed at the bottom and passed the fuel channels in an upward direction, and was thereby heated up from 220 °C to 385 °C. It had a pressure of 60 bar and was circulated by two blowers with water sealed glands. The heat was transferred to two steam generators.

After commissioning in 1968 the plant was operated satisfactorily for more than 2 months with full power followed by a planned shut-down period of nearly 3 months for modification and revision work. On January 21, 1969 the reactor was restarted. When it reached a thermal power of 12 MW the accident occurred, resulting in a rapid depressurization of the primary circuit. Within 10 minutes the balance pressure in the reactor cavity was reached. A high level of radioactivity was detected first in the primary circuit and later in the cavity indicating that one or more fuel elements had been damaged. The loss of heavy water revealed that the moderator tank had also become defective. At the very beginning of the accident the reactor was tripped and the cavity closed. All the safety equipment worked well.

The initial radiation level in the reactor cavity exceeded 100 R/h. It was caused by short-lived nuclides (Rb 88, Kr 88). A small quantity of radioactivity entered into the machine cavity via leakages and in the exhaust air to the stack.

The cause and progress of the accident could only be clarified by a detailed and thorough investigation which took nearly 10 years. The most likely initiating event was a water ingress into the primary circuit via a blower seal. The water got into some fuel assemblies where it remained for about five weeks leading to corrosion of the magnesium fins and claddings. The corrosion products mostly settled down at the lower end of the cooling channels and greatly reduced the flow area.

At the reactor start the cooling of one assembly was impaired so much that with increasing reactor power single segments were overheated. Shortly before the reactor power stabilized at 12 MW melting of the central fuel rod must have happened. Melting propagated to one or two peripheral channels where the molten metals started to burn in CO_2. The enormous heat produced by the burning resulted in a distortion of the graphite column which then must have touched the pressure tube heating this up to bursting temperature. The tube burst and destroyed the surrounding calandria tube leading to a blow-down of the coolant into the moderator tank. Shortly before, the reactor had been tripped by the high level of radioactivity released into the primary circuit by the burning fuel.

The rapid pressure build-up in the moderator tank opened one of the five rupture discs and resulted in a considerable deformation of the interior. A few seconds later a second and higher pressure peak must have occurred caused by an explosive chemical reaction between heavy water and hot liquid metals. The liquid metals had collected in the bottom part of the fuel assembly and had melted two holes through the pressure and calandria tube via which it was injected into the water. The second pressure peak resulted in a collapse of some calandria tubes and thereby in a jamming of some shut-down rods in the fully-in position.

2.5 Three Mile Island Block 2 (TMI 2)

TMI 2 is a nuclear power station with a pressurized water reactor (PWR) of 2800 MW as the heat source /9/. The power station was commissioned in 1978, i.e. one year before the accident happened. The primary system consists of two loops each containing a steam generator via which the reactor power is transferred to the secondary water-steam circuit. One of the loops is shown in Fig. 5 together with the other systems which played a significant role in the accident.

One important component was the pressurizer, a vessel half filled with water which has a temperature that produces a steam pressure of 152 bar above the water level. At the bottom end, the vessel is connected to the hot leg of one loop by a syphon. To cope with rapid pressure transients the pressurizer is fitted with a pilot-operated relief valve. In the case of a failure of the relief valve the line can be closed by an upstream block valve. Three safety valves protect the pressurizer from too high pressure. All valves blow down in a drain tank where the steam is condensed in a water pool. A safety valve and rupture discs protect the tank from too high pressure and discharge, if occasion arises, into the containment.

The straight-tube steam generator has the advantage of producing superheated steam. On the other hand, the water content on the secondary side is very low. Consequently a malfunction of the feed water system encroaches very quickly on the primary system. Another significant aspect of the feed water system is the fact that it is needed for after-heat removal with an intact primary circuit since temperature and pressure of the primary water must be reduced via the steam generators before the separate after-heat removal system of the primary circuit can be started. TMI 2 has thus besides the main feed water system an auxiliary system as is shown in Fig. 5.

To cope with leaks in the primary circuit the plant has two high-pressure and two low-pressure injection systems. Both are switched on automatically, the high-pressure system when for instance the pressure in the primary circuit drops to 110 bar. The high pressure system is combined with the make-up system which means that the pumps were designed for a head of 200 bar. This circumstance turned out to be disastrous in the accident.

As in many PWR's the water inventory is controlled by the water level of the pressurizer. In this connection one has to bear in mind that due to the syphon the level indicator acts like a manometer. It balances the pressure between the pressurizer and the primary circuit but gives no indication whether the circuit is filled with steam or water. This fact was also very important for the occurrence of the accident.

The accident in TMI 2 was initiated at 04.00 on March 28, 1979 by a malfunction in the main feed water system, leading to a simultaneous shut-down of both main feed water pumps /10/. The reactor protection system responded correctly by shutting-down the turbine, opening the turbine by-pass and switching on the auxiliary feed water system. The pumps started but flow could not be established because the valves in the feed line were falsely closed. Eight minutes elapsed before the error was detected and corrected.

The missing feed water supply impaired the heat removal from the primary circuit. Consequently the temperatures rose and the thermal expansion of the water resulted in a pressure increase of the pressurizer. After 3 sec the relief valve opened and after 9 sec the reactor was tripped. During the subsequent pressure drop the relief valve failed to close, which the operator did not realize since the valve position was not indicated. After 2 minutes the high-pressure injection pumps started automatically and injected cold water into the primary system. From the fact that the pressurizer was completely filled with water after 4 minutes the staff falsely concluded the primary system was filled with water and switched off the high-pressure pumps. They feared that a continuing operation of the pumps could open the safety valves.

The failure of the relief valve resulted in a continuous loss of water from the primary circuit by vaporization. The steam was discharged into the closed containment via the pressurizer and the drain tank, the rupture disc of which had burst due to the excess amount of steam. The loss of water was accelerated by the circumstance that the steam pressure on the secondary side of the steam generator was not reduced. Consequently the primary pressure could not drop below 70 bar. After 1 hour and 40 minutes the last two circulation pumps were switched off due to cavitation. Up to this time the core was still sufficiently cooled by a water-steam mixture. But then the water level started to drop below the top end of the core. The uncovered parts of the fuel rods were gradually overheated whereby additional heat and hydrogen were produced by chemical reaction between steam and the zircaloy cladding. Severe core damage occurred which could not be prevented by closing the relief line after 2.3 hours.

As is concluded from the condition of the core found later by the inspection of the pressure vessel interior, a zone of molten material must have been formed in the core centre before the core was reflooded by switching on one circulation pump, which happened after 3 hours for about 15 minutes /11/. The molten zone solidified by reflooding and the vibration caused crumbled the embrittled fuel rods of the upper part of the core, which then formed a debris bed on the solidified material, as is shown in Fig. 6. Later the solidified material melted again and the hot molten material dropped into the bottom part of the pressure vessel, where it solidified mostly to fist-sized lumps in the residual water. At 3 hours and 30 minutes the high-pressure system was switched on and core cooling was restored, preventing the core from melting completely.

In the course of the accident, $9 \cdot 10^{16}$ Bq to $5 \cdot 10^{17}$ Bq of the radioactive noble gases xenon and krypton were released into the environment, but only about $6 \cdot 10^{11}$ Bq (17 Ci) of radioactive iodine was released /12/. The fact that in spite of the closure of the containment radioactive substances escaped into the environment is attributed to the circumstance that highly contaminated sump water was pumped to the waste treatment system in the auxiliary building within the first 5 hours of the accident. Insufficient hold-up tanks on line resulted in an overflow to the building floor. Outgassing from this water and discharge through the ventilation system and filters caused the offsite release.

2.6 Chernobyl 4

Chernobyl 4 belongs to a special Russian reactor line, the RBMK 1000, which is only used in the Soviet Union /13/. The RBMK 1000 is a graphite-moderated pressure tube boiling water reactor with a thermal power of 3200 MW. In 1984 twelve units were in operation, four of them in Chernobyl, 100 km north of Kiev. The Chernobyl unit No. 4 was commissioned in 1983.

The reactor consists of a large cylindrical graphite pile (14 m diameter, 8.5 m height), which rests on a bottom shielding plate as shown in Fig. 7. At the top the pile is covered by a shielding slab supported by a lateral cylindrical shielding wall. A compensator-like iron shroud welded to both plates envelops the pile. The gas-tight room thus formed is filled with inert gas of low overpressure compared with atmospheric pressure.

The graphite pile is vertically penetrated by about 1700 pressure tubes, made from zirconium alloy in the pile and stainless steel out of it. Each pressure tube contains one fuel element consisting of two bundles with 18 rods each. The rod cladding is made from the same zirconium alloy as the pressure tubes. Thus a lot of zirconium is contained in the core. The fuel is UO_2 with an initial enrichment of 1.8 %.

The reactor is controlled by 211 vertical absorber rods housed in additional pressure tubes. The absorber rods are subdivided into five groups according to their function. One group is used as an automatic scram system, but the rods need 20 s to drop fully into the core. The lack of a real fast shut-down system is one deficiency that contributed to the accident. The other deficiency important for the accident is the positive void coefficient of reactivity of the H_2O, the coolant for the fuel elements. The reason for the positive void coefficient is the same as in the NRX. The void coefficient increases with increasing burn-up and with the removal of absorber rods from the core. Also the temperature coefficient of reactivity of the graphite moderator is positive. All this together with the size of the core results in a very unstable reactor, which requires a complicated control system for stabilization.

The reactor is housed in a pit of concrete walls. The room as well as the other rooms in which aggregates and pipes of the internal cooling loops are housed are gas-tight and partially designed to withstand an internal pressure of 4 to 5 bar. In the basement of the reactor building there is a pressure suppression system consisting of water ponds in which the steam-air mixture is fed in the case of a pipe fracture. A containment in the ordinary sense does not exist because it was considered unnecessary.

The accident was initiated by a rundown test of the turbine generator /14/. The aim of this test was to see how long a main feed water pump could be powered from the rotation energy of the turbine generator rotor in the event of a loss of offsite power. The pumps are part of a quick acting emergency feed water system (see Fig. 8), which is needed as a back-up system after a large pipe fracture in a loop, but only for a short interval of 45 to 50 s. Then the long-term emergency cooling system will be in operation. Earlier tests in 1982 and 1984 had failed. Now the operators were so determined to complete the test that they violated many operating rules and procedures.

At the time of the test the reactor was in a very unstable and dangerous condition. Instead of thirty absorber rods as the regulations required only eight were in the core. The others were withdrawn to compensate for the high xenon poisoning and other effects which consumed excess reactivity. In addition, the absorber rods of the global automatic regulation system, which at the time controlled the reactor power, were in a lower reactor position. The reactor was operated only at 200 MWt since a higher power was prevented by the small excess reactivity available. In both loops all four circulation pumps were operating to provide for safe core cooling after the test since two pumps of each loop were connected to the busbar of the turbine generator and would run down with the turbine. Owing to the low power and the inadmissably high flow rate the steam content in the core was very low. Several trip signals associated with parameters in the cooling loops were disconnected in order to avoid a reactor trip before the test could be performed. The fact that the emergency cooling system pumps were disconnected was in accordance with the experimental programme.

At 1:23:04 the test began when the staff closed the emergency regulating valves on the running turbine. The reactor continued to operate at a power of 200 MWt since the trip signal from the closing of the valves had been blocked so the test could be repeated in case it failed the first time. When the pumps began to run down, flow was reduced, the coolant boiled and the reactor power began to rise slowly.

The steam formation resulted in a further reduction of flow which again together with the rising power enhanced the steam production and so on. The automatic control system was not able to compensate the reactivity increase caused by the growing steam content in the channels. At 1:23:40 the reactor was scrammed manually, but in vain: because of the position and the slow movement the absorber rods proved to be inefficient. The reactor became prompt cirtical. Its power shot up to 100 times the nominal reactor power within a few seconds. The energy density in the fuel reached a value where the fuel disintegrated - in effect, exploded. The interaction of the hot fuel particles with the water led to an abrupt increase of pressure in the fuel channels, destruction of the channels, and finally an explosion which destroyed the reactor and part of the building and ejected fuel and graphite blocks into the environment. A few seconds later a second explosion occurred but it is still unclear whether it was a second power excursion or an explosion of hydrogen formed by metal-steam reaction.

The fire which broke out immediately at over 30 places in and outside the reactor building was extinguished by about 05.00. But the smothering of the graphite fire in the pile took several days. It was achieved by covering the damaged reactor with compounds of boron, dolomite, sand, clay and lead dropped from helicopters. About 5000 t in all was dropped between April 27 and May 10, mostly between April 28 and May 2. The layer acts as a filter having reduced the release of radioactive substances from the pile to a few hundred Ci per day by May 6. The problem of reducing the fuel temperature was solved at the same time by pumping nitrogen from the compressor station into the space beneath the reactor vault.

First estimates by the Soviets revealed that 3.5 % to 4 % of the fuel was released from the reactor, with 0.3 % to 0.4 % dispersed on site and 1.5 % in a 20 km zone around the site. The fuel is believed to have remained in the bottom of the reactor well and adjacent piping with a limited quantity in the steam drums. Visual examination confirmed that about 10 % of the graphite had been ejected from the reactor building. About 25 % of the total graphite was estimated to have been consumed in the graphite fire.

Table 3 shows the quantities of radioactive substances released into the environment in the first stage of the accident and in the period from April 27 to May 6. The values were estimated by the Soviets on the basis of their own measurements, with a 50 % error margin. They correspond quite well with the values which were calculated by German scientists on the basis of the fallout over western and northern Europe. In total about $2 \cdot 10^{18}$ Bq excluding noble gases were released before May 6, the day the release of radioactive materials virtually ceased.

3. ENVIRONMENTAL CONSEQUENCES OF THE ACCIDENTS

Apart from the Chernobyl catastrophe, only the accident in Windscale had major radiological consequences for the environment. In the other cases the radioactive materials released from the damaged core were almost completely retained in the reactor building. In this respect the containment of TMI 2 proved good. Without the containment this accident would also have been a catastrophe. So the maximum individual whole body dose did not exceed half the value of the annual dose by natural radiation. From the collective dose the US Health Authority calculated one additional cancer death in a period of 30 years.

In the Windscale accident the radioactive materials were released into the atmosphere via the 130 m stack and were subsequently dispersed and deposited over England, Wales and over parts of northern Europe. Already in the early stage of the accident iodine 131 was identified as the most important nuclide as far as health consequences to the population were concerned. Restrictions were imposed on the distribution of milk to reduce intakes by the local population of radioiodine via the pasture-cow-milk pathway. These restrictions were introduced 1 to 3 days after the first release and the final area restricted was 520 km^2. In the most contaminated area, close to Windscale, milk distribution was not resumed until 44 days later. Owing to the milk ban the average radiation doses to the thyroids of the local population were typically 5 to 20 mSv for adults and 10 to 60 mSv for children. The highest child thyroid doses inferred from measured thyroid activity were 160 mSv, which is attributed to the fact that the milk ban was not completely effective. A comprehensive assessment most recently published /4/ showed that the collective effective doses were in the order of 10^3 manSv, to which the ingestion of contaminated milk contributed the most. The total number of additional thyroid cancers caused by the accident in the United Kingdom population is expected to be 260 (13 of which will be fatal). This figure must be compared with the 660 thyroid cancer incidents per year in England and Wales.

The high quantities of radioactive materials released in the first stage of the Chernobyl accident required immediate measures to protect the population around the plant /14/. After potassium iodide pills had been distributed to the 45,000 inhabitants of Pripyat, the nearest town to the plant, evacuation began by 11 a.m. April 27 and was finished 2 1/2 hours later. Another 90,000 people were evacuated in the next 10 days from the surrounding areas including the town of Chernobyl 15 km away, so that altogether about 135,000 people were evacuated from a 30 km radius area. The Russian criteria require action when the predicted whole-body doses exceed 0.75 Sv. It is estimated that groups of the later evacuees received external doses of 0.3 to 0.5 Sv and 10 times that to the thyroid from inhalation. These doses would be twice as high as those to the Pripyat inhabitants.

The main zones of ground contamination after the accident were to the west, north-west and north-east of the plant, as is shown in Fig. 9 . Radiation levels near the plant exceeded 100 mR/h. On the western track the maximum radiation levels 15 days after the accident were 5 mR/h at a distance of 50 to 60 km, and the same to the north at a distance of 35 to 40 km. In Kiev the radiation levels at the beginning of May reached 0.5 to 0.8 mR/h.

The collective doses over the next 50 years will be determined by internal exposure. Soviet experts calculated a value of about $2 \cdot 10^6$ manSv, whereas the collective doses from external exposure are expected to be a tenth of that value. But there are indications that the figure for the internal exposure may be too high by a factor of at least 10. This, in turn would lower the Soviet estimate of cancer fatalities in the Soviet Union from Chernobyl by an order of magnitude, from some 25,000 to several thousand.

4. LESSONS TO BE LEARNT FROM THE ACCIDENTS

The description of the accidents already reveals that the combination of design deficiencies and human errors played an important role in the occurrence of the accidents. This underlines the significance of adequate qualifications and training for the staff. Apart from the accident in Lucens, doubt exists as to whether the staff of the plants concerned were trained in the right manner. It seems to be clear that in almost all cases the staff were not familiar with the special physical properties of the individual system.

For the design and layout of a fission reactor the following conclusions must be drawn:

- the core should not allow for an autocatalytic nuclear reaction, which means that it should be self-stabilizing at least under normal operating conditions,
- the safety equipment must be adequately designed to meet the safety requirements of the special system,
- there should always be enough shut-down reactivity so that the removal of a single absorber rod cannot lead to criticality,
- all important safety parameters must be directly measured and the condition of the plant should be presented by clear and easily understandable information,
- the combination of safety and operational systems must be avoided, at least if this impairs the safety, and
- an adequate automatic interlock system must exist as a provision against human error.

The last measure, of course, is no universal remedy against human errors. In some countries much effort is thus spent on the development of a so-called forgiving nuclear reactor. The small HTR developed in the Federal Republic of Germany is an example of such a system.

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Reactor Country	NRX Canada	Wind-scale-I UK	SL-1 USA	Lucens Switzerl.	TMI-2 USA	Chernobyl USSR
Purpose	Research Reactor	Pu-Production	Test Power Sta.	Test Power Sta.	Power Station	Power Station
Application	civilian	military	military	civilian	civilian	civilian
Commissioning		1951	1958	1968	1978	1983
Reactor Data						
Therm. Power [MW]	30	?	3	30	2800	3200
Moderator	D_2O	Graphite	H_2O	D_2O	H_2O	Graphite
Coolant	River Water	Air	H_2O	CO_2	H_2O	H_2O
Coolant-Boundary	Tubes	Channels	Tank	Tubes	Tank	Tubes
U-235-Content	0,7%	?	91%	0,96%	3%	2%
Fuel Matrix	U-Metal	U-Metal	U Al-Metal	U-Metal	UO_2	UO_2
Cadding Material	Al	Li-Mg-Alloy	Al-Ni-Alloy	Mg-Alloy	Zirconium	Zirconium
Fuel Geometry	Rods	Pins	Plates	Pins	Pins	Pins
Accident						
Date	Dec. 12/52	Oct. 8/57	Jan. 3/61	Jan. 21/69	Mar. 29/79	Apr. 26/86
Cause	Stuck-Rods Absorber Removal	Wigner Energy	Absorber Removal	Channel Blockage	Feed-Water Loss	Insufficient Cooling
Power Excursion	nuclear	chem.	nuclear	no	no	nuclear
Peak Power [MW]	80	?	19,000	—	—	320,000
Energy [MWs]	2000	?	130 ± 20%	—	—	?
Steam Explosion	no	—	yes	no	no	yes
Peak Pressure [bar]	3-4	—	~ 700	16-25	—	?
Metal-Water Reaction	yes	—	yes	yes	yes	yes
Chemical Explosion	in Pile	—	no	in Pile	out of Pile	in/out of Pile
Peak Fuel Temp. [K]	1400	red-hot	> 2000	?	> 2000	~ 3000
Post Accident Core Condition	22 FE* damaged	150 FE* damaged	20% molt.	1 FE* destroyed	> 20% molt. / debris bed	completely damaged
Radiological Consequences						
Maximum Individual Doses** [m Sv]	?	Thyroid : 160	in 10 Days 0.1	0.05	0.5	300-500
Collective Doses** [man Sv]	?	$1.2 \cdot 10^3$	?	negligible	10^2	$2 \cdot 10^6$
Expected Late Fatalities	?	13	?	0	1	25,000

* FE : Fuel Element ** Whole Body , if not Specified

Major Reactor Accidents and Reactors Concerned

Table 1

Estimates of Radionuclides Released in the Windscale Accident

Nuclide	Ratios to ^{131}I
^{85}Kr	$9.8 \cdot 10^{-2}$
^{89}Sr	$4.1 \cdot 10^{-3}$
^{90}Sr	$1.0 \cdot 10^{-4}$
^{95}Zr	$1.3 \cdot 10^{-2}$
^{99}Mo	$6.0 \cdot 10^{-2}$
^{103}Ru	$6.7 \cdot 10^{-2}$
^{106}Ru	$4.1 \cdot 10^{-3}$
* ^{131}I	1.0
^{132}Te	$5.9 \cdot 10^{-1}$
^{133}Xe	$2.1 \cdot 10^{1}$
^{134}Cs	$2.0 \cdot 10^{-3}$
^{137}Cs	$3.0 \cdot 10^{-2}$
^{140}Ba	$1.1 \cdot 10^{-2}$
^{141}Ce	$1.2 \cdot 10^{-2}$
^{144}Ce	$4.1 \cdot 10^{-3}$

* ^{131}Iodine : $6 \cdot 10^{14}$ Bq = $1.6 \cdot 10^{4}$ Ci

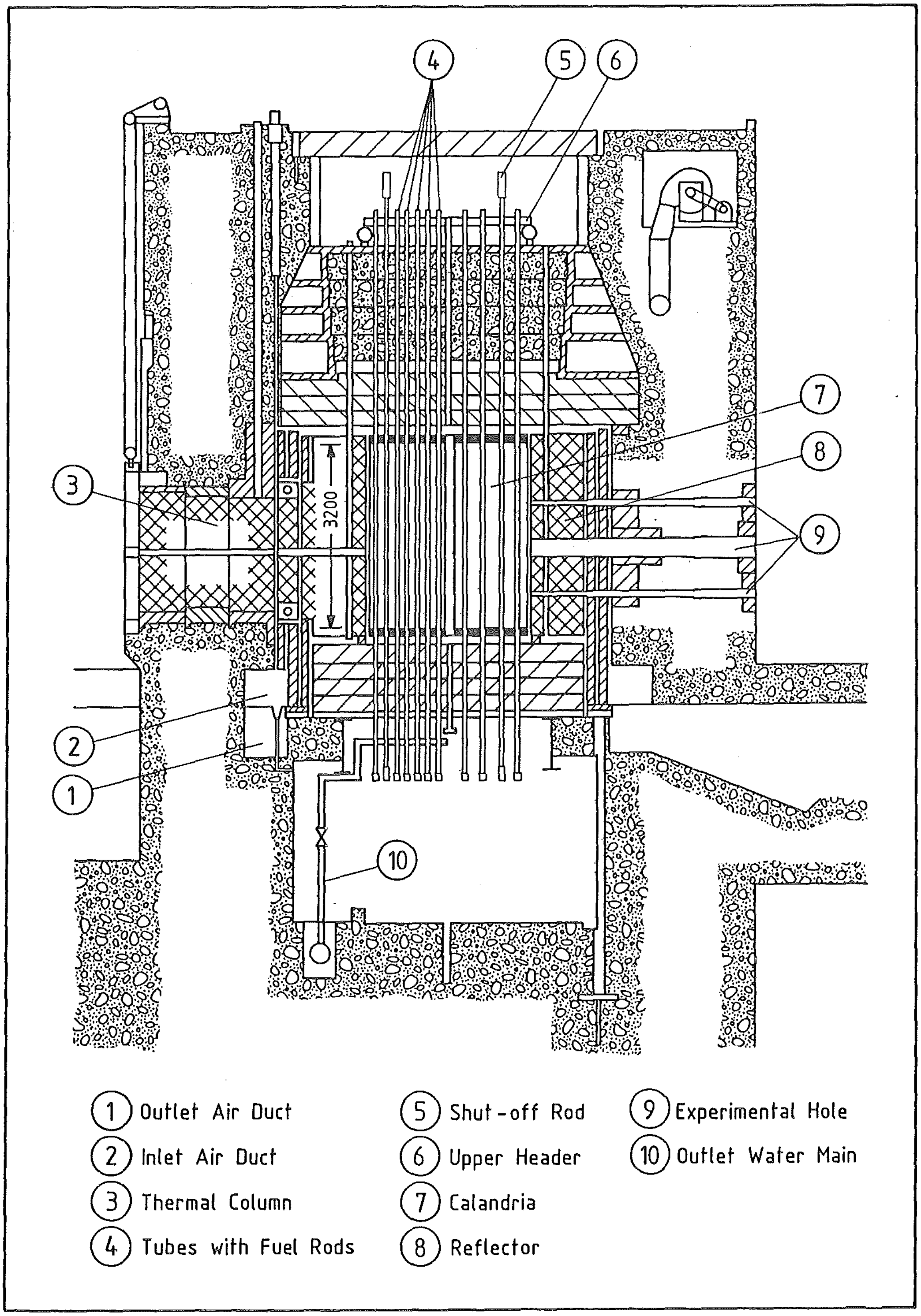
Table 2

Release of Radioactive Materials into the Environment from the Damaged Chernobyl No. 4 Plant

Radio-Isotope	Released Radioactivity [Mega Ci]		Fraction [%] of Core Inventory
	on April 26	from April 27 to May 6	
^{133}Xe	**5**	**45**	**up to 100**
^{85m}Kr	0,15	–	,, 100
^{85}Kr	–	0,9	,, 100
^{131}I	**4,5**	**7,3**	**20**
^{132}Te	4	1,3	15
^{134}Cs	0,15	0,5	10
^{137}Cs	**0,3**	**1,0**	**13**
^{99}Mo	0,45	3,0	2,3
^{95}Zr	0,45	3,8	3,2
^{103}Ru	0,6	3,2	2,9
^{106}Ru	0,2	1,6	2,9
^{140}Ba	0,5	4,3	5,6
^{141}Ce	0,4	2,8	2,3
^{144}Ce	0,45	2,4	2,8
^{89}Sr	**0,25**	**2,2**	**4,0**
^{90}Sr	**0,015**	**0,22**	**4,0**
^{238}Pu	$0{,}1 \cdot 10^{-3}$	$0{,}8 \cdot 10^{-3}$	3,0
^{239}Pu	**$0{,}1 \cdot 10^{-3}$**	**$0{,}7 \cdot 10^{-3}$**	**3,0**
^{240}Pu	$0{,}2 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	3,0
^{241}Pu	0,02	0,14	3,0
^{242}Pu	$0{,}3 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	3,0
^{242}Cm	$0{,}3 \cdot 10^{-2}$	$2{,}1 \cdot 10^{-2}$	3,0
^{239}Np	2,7	1,2	3,2

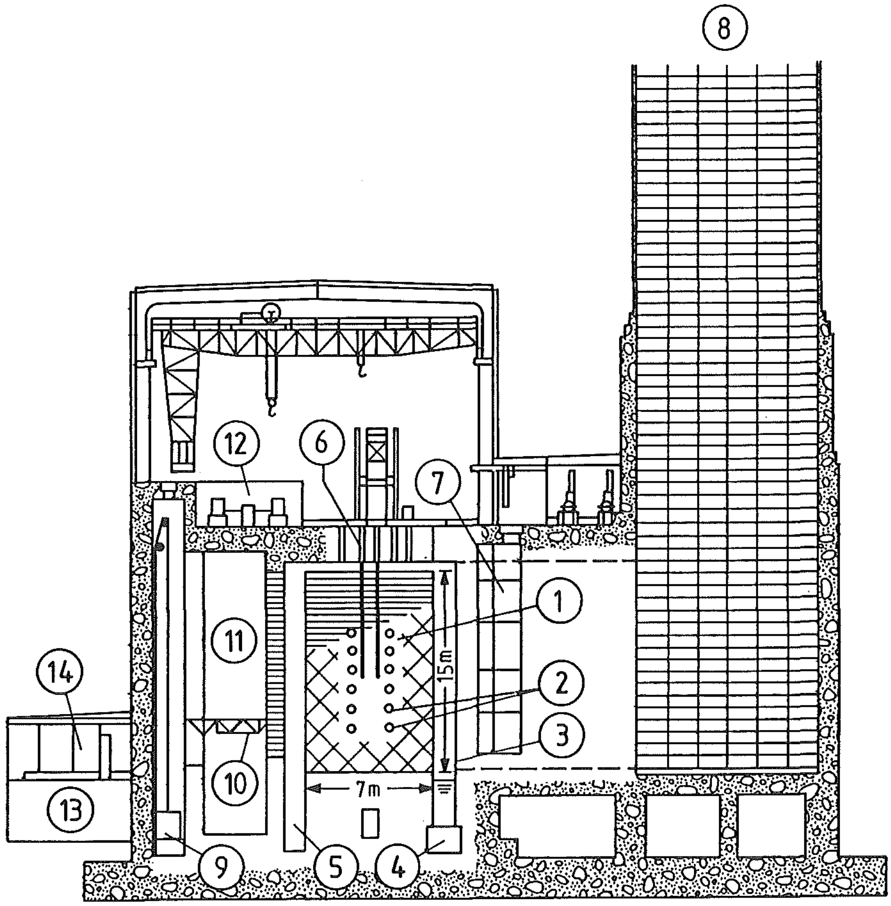
* Uncertainty ± 50 % . Only Soviet Measurements taken into account .

Table 3



Vertical Cross Section of the Canadian Research Reactor NRX

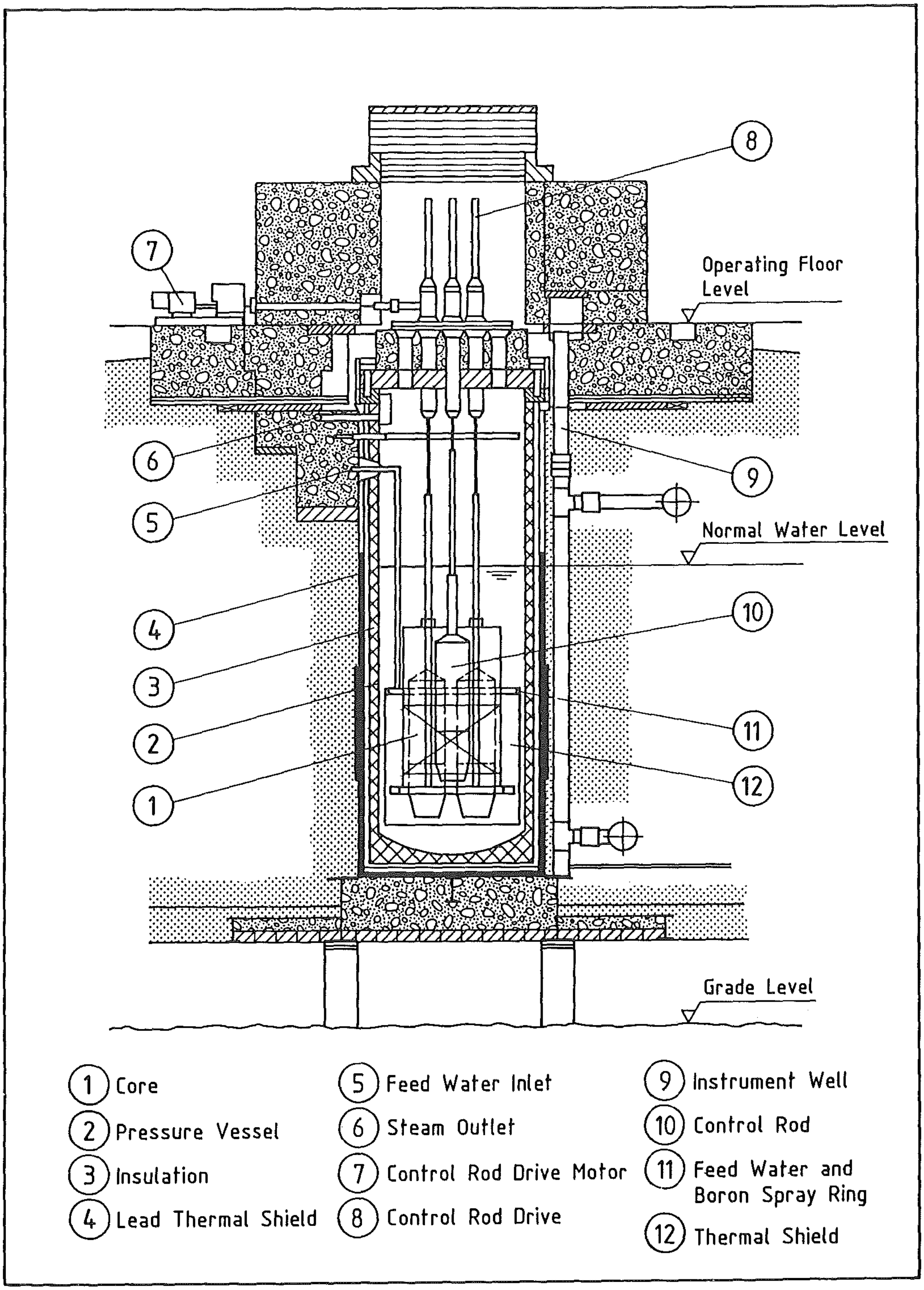
Fig. 1



1 Graphite Core
2 Control Rods
3 Discharge Face
4 Water Duct
5 Charge Face
6 Shut-off Rods
7 Exit Air Analysers
8 Chimney
9 Passenger & Goods Lift
10 Platform
11 Charge Hoist
12 Hoist Gear
13 Slug Store
14 Control Room

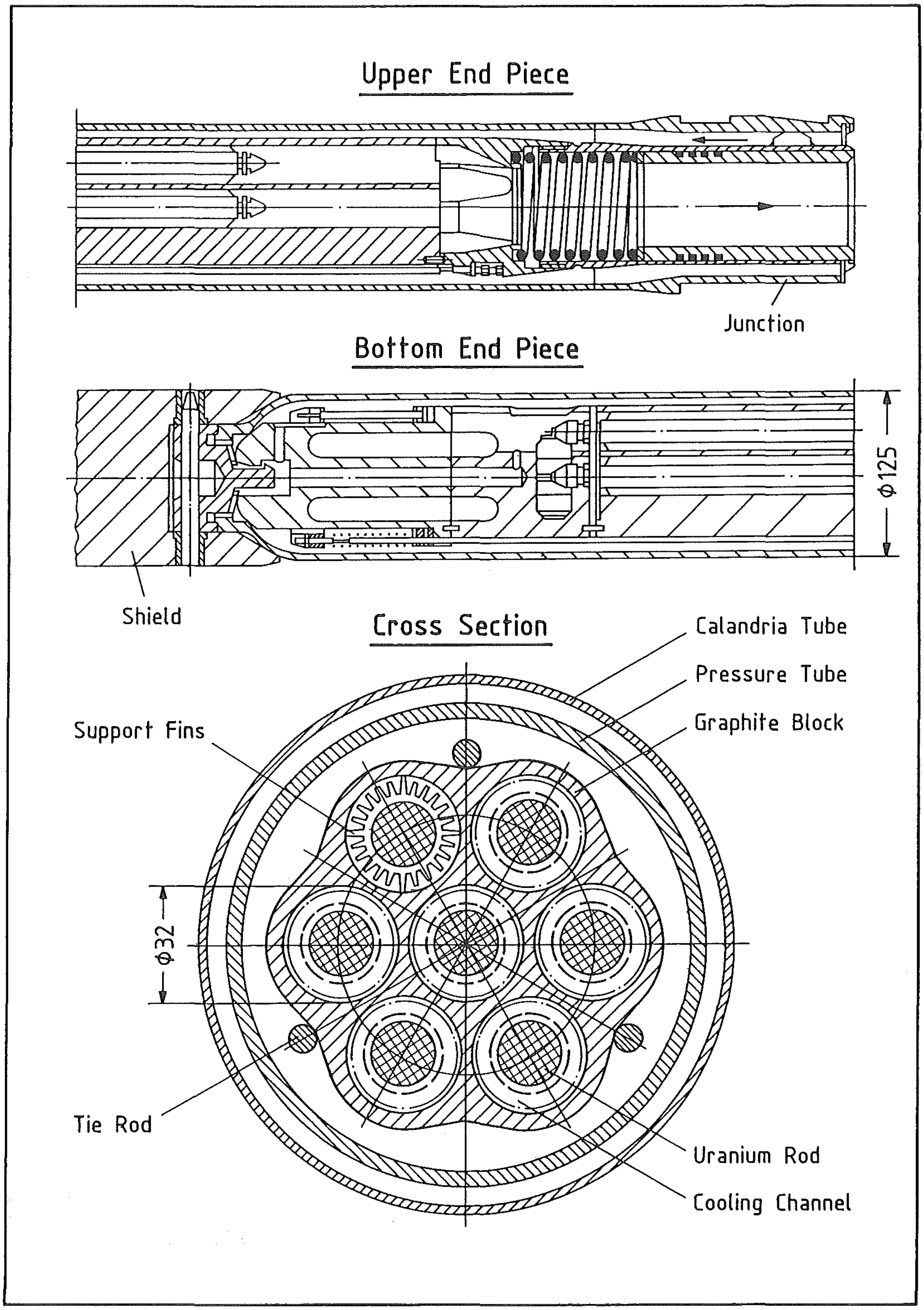
Sectional View of the Windscale Graphite Reactor

Fig. 2



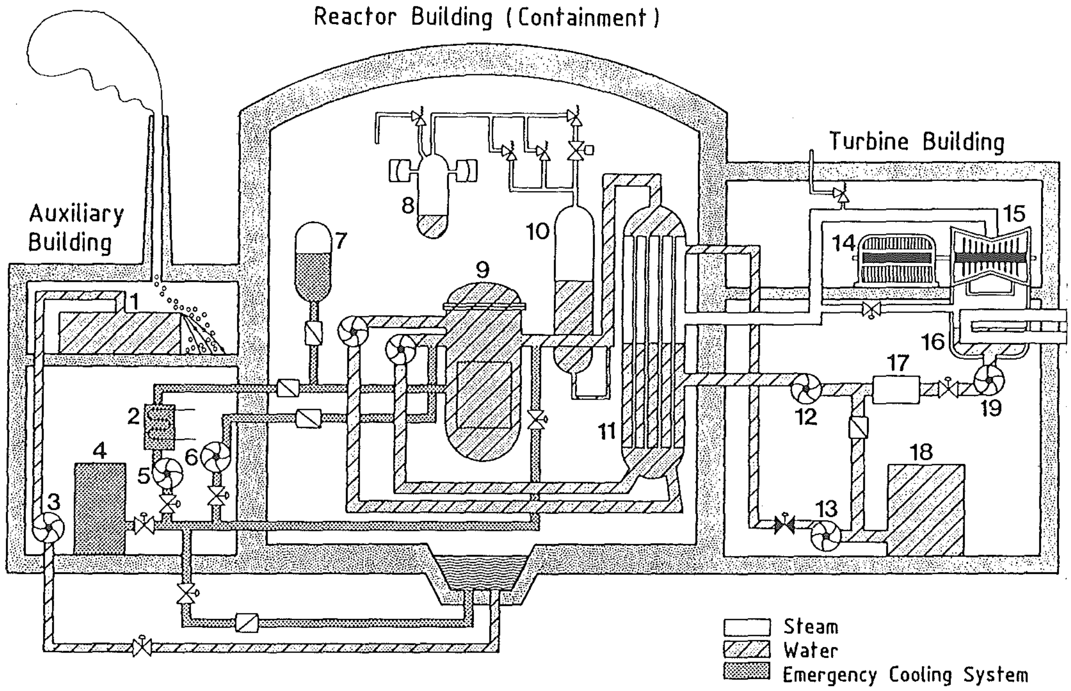
Vertical Section of the SL-1-Reactor

Fig. 3



Arrangement of a Fuel Element in a Pressure Tube of the Lucens Reactor

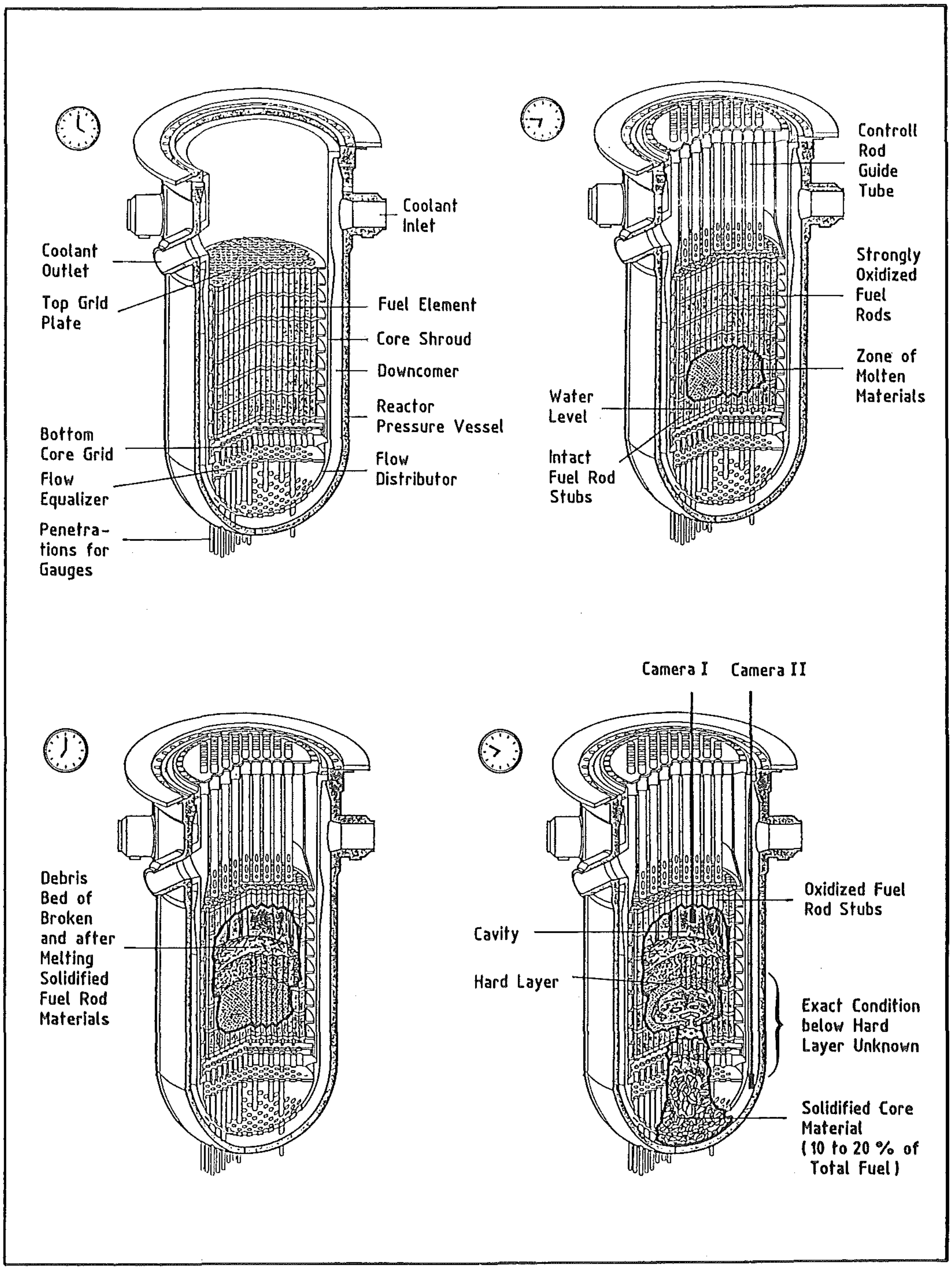
Fig. 4



1 Waste Water Tank
2 Cooler
3 Sump Pump
4 Make up Tank
5 Low - Pressure Injection Pump
6 High - Pressure Injection Pump
7 Core Flood Tank
8 Drain Tank
9 Reactor Pressure Vessel
10 Pressurizer
11 Steam Generator
12 Main Feed Water Pump
13 Auxiliary Feed Water Pump
14 Generator
15 Turbine
16 Condenser
17 Condensate Purification Plant
18 Condensate Tank
19 Condensate Pump

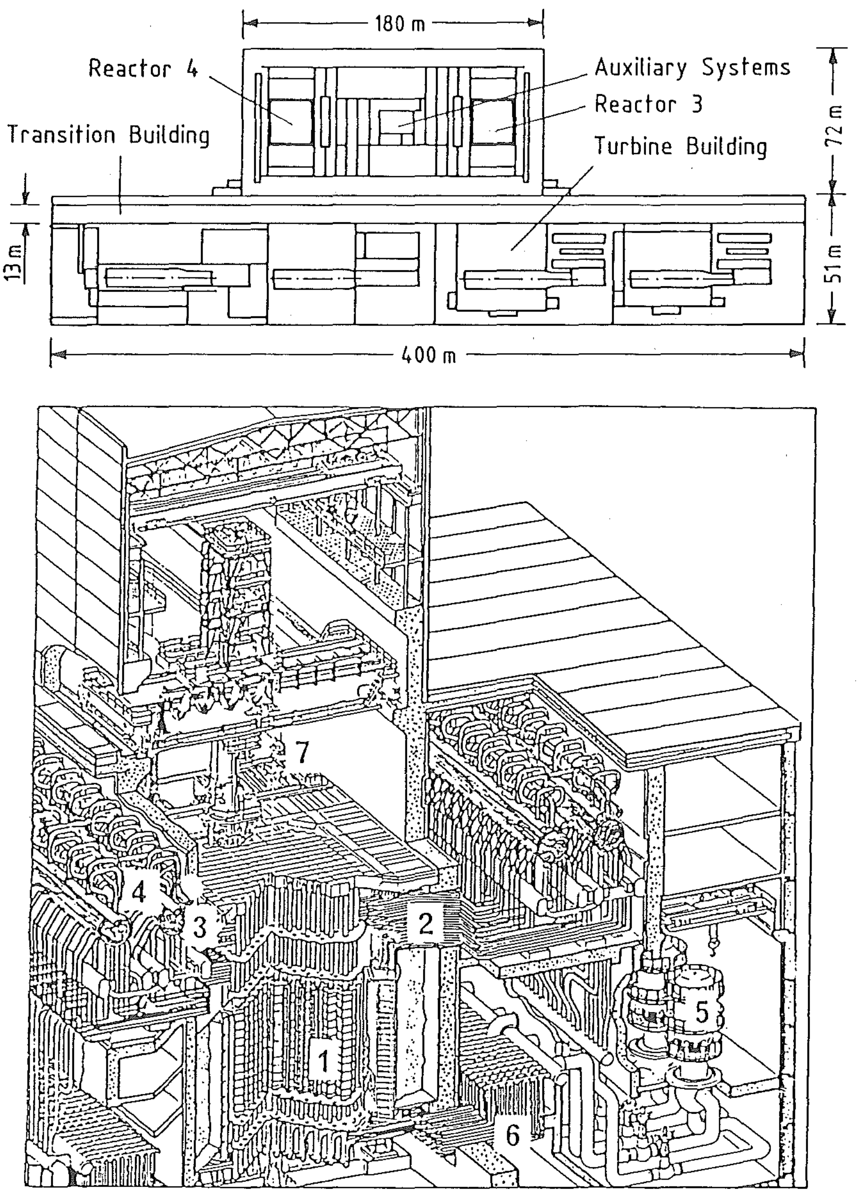
Schematic Diagram of Important Systems of the TMI - 2 Plant

Fig. 5



Steps of Core - Damaging in TMI - 2

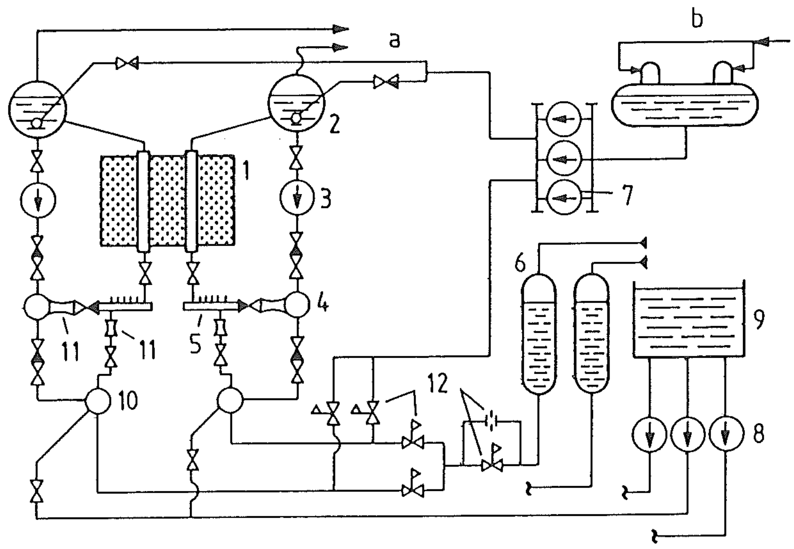
Fig. 6



1 Reactor
2 Pipes (Reactor Outlet)
3 Steam Drums
4 Steam Pipes
5 Circulation Pumps
6 Pipes (Reactor Inlet)
7 Fuel Storage

Plane and Perspective View of the Chernobyl 3 and 4 Plant

Fig. 7



1 Reactor
2 Steam Drum
3 Circulation Pump
4 Main Header
5 Subheader
6 Pressurized Water Reservoir
7 Main Feed Water Pump
8 Long-Term ECCS Pump
9 Condenser Pond
10 ECCS Subheader
11 Flow Restricter
12 Fast Acting Valve

a to Turbine
b from Condenser

Main Circulation Loops and Emergency Core Cooling System (ECCS)

Fig. 8

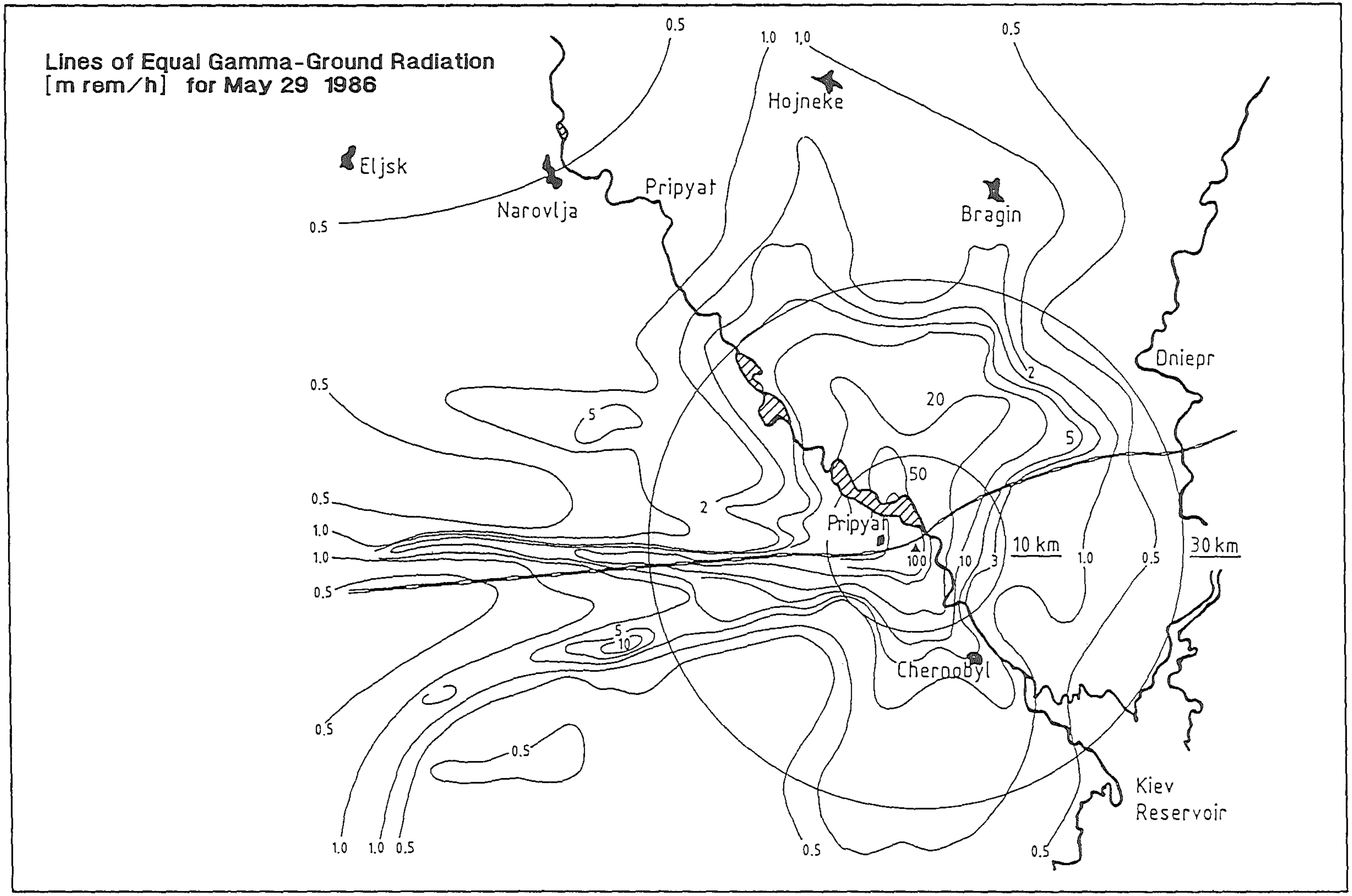

Lines of Equal Gamma-Ground Radiation
[m rem/h] for May 29 1986
Eljsk
Narovlja
Pripyat
Hojneke
Bragin
Dniepr
Pripyat
Chernobyl
Kiev
Reservoir
10 km
30 km
0.5
1.0
2
5
10
20
50
100
3

Fig. 9

Emergency Planning and Preparedness for Nuclear Facilities

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1. INTRODUCTION AND DEFINITIONS

Emergency protection measures are the necessary administrative supplement to the technical measures of engineered reactor safety to reduce the effects of nuclear accidents.

In the Federal Republic of Germany by law we have to do emergency planning and to prepare emergency protection measures for all potentially dangerous installations both conventional and nuclear independent of the probability of an accident.

The fact that there are definitions of such terms as "incident," "accident," "catastrophe," does not mean that these events are bound to occur in nuclear facilities. On the other hand, there can be no absolute safety in any technical sector. Nuclear installations are designed, constructed and operated in such a way that the probability for an incident or accident is very low and the probability for a severe accident with catastrophic consequences is extremely small. These accidents represent the residual risk of the nuclear installation, and this residual risk can be decreased on one hand by a better design, construction and operation and on the other hand by planning and taking emergency measures inside the facility and in the environment of the facility.

By way of introduction and definition it may be indicated to define some terms pertaining to the subject in order to make for more uniform understanding. For there is often a lack of clarity with respect to the meanings of the terms "incident," "accident," "catastrophe" not only in different countries but also in the minds of different people.

- Incident

In the Federal Republic of Germany the Radiation Protection Ordinance (BUND 76) offers a definition of an incident in the nuclear field.

> An incident is a sequence of events the occurrence of which does not allow operation of the plant or the activity to be continued for safety reasons, and for which the plant has been designed, or for which precautionary measures have been taken in the performance of the activity.

- Accident

Definitions of the term "accident" can be found in the Basic Safety Standards of the Commission of the European Communities (CEC 80) or, again, in the Radiation Protection Ordinance of the Federal Republic of Germany:

> EC:
> An unforeseen event that causes damage to an installation or disrupts the normal operation of an installation, and is likely to result for one or more persons in a dose exceeding the maximum permissible doses.
>
> Federal Republic of Germany:
> Sequence of events which can cause one or more persons to undergo a radiation exposure or incorporate radioactive substances in excess of the prescribed limits, unless classified as an incident.

Both definitions differ from the customary definition of an accident because, for an accident in the nuclear field, it is already sufficient if there is a **possibility** of a limit being exceeded.

This clarification of the terminology by legal definition also affected the safety criteria, with respect to the technical design of nuclear power plants for incident situations to be brought under control, not using the term "maximum credible **accident**" but "design basis **incident**."

- Catastrophe

With respect to the term "catastrophe" I am not able to present any official definition. Oxford English Dictionary defines:

> "final event, conclusion generally unhappy (disastrous end, finish up, ruin, calamitous fate)"

and Grand Larousse

> "grand malheur qui vient subitement bouleverser la vie d'une personne ou d'une société, spécialement: événement inattendu causant la mort de plusieurs personnes."

A more comprehensive definition could be this:

> "A catastrophe is an event caused by extensive occurrences which can be traced back to natural elements or adverse conditions in traffic or in industry and which damages or jeopardizes the lives and health of numerous people, valuable property or the supply of the public."

I feel that in the public debate about nuclear technology in some countries certain mass media and environmentalists will already use the term "nuclear catastrophe" if, in the sense of the above definition, merely an incident has occurred.

- Limits

The above definitions of incidents and accidents result in the following dose levels, according to the dose limits pertaining in the Basic Safety Standards of the Commission of the European Communities or the Radiation Protection Ordinance of the Federal Republic of Germany, exceeding which will constitute an accident.

	EC annual dose limits mSv/a	FRG dose commitment limits mSv
Whole body, bone marrow, gonads		50
effective dose	5	
Skin, bones	50	300
Extremities	50	600
Thyroid	50	150
Other organs	50	150

Table 1: Annual dose (European Communities) and dose commitment (Federal Republic of Germany) limits for members of the public for the design basis incident of nuclear facilities.

2. ACCIDENT CONSEQUENCES

In case of an accidental release from a nuclear power plant the radioactive nuclides will be transported to the environment. The amount of activity release, the time dependence and the release pathes from the core to the environment may differ in a broad range depending on the actual accident sequence. Details are given in risk analysis studies (e.g. NRC 75, DRS 79). Confining oneself to the atmospheric release which is most relevant, essentially five principal pathways can cause an exposure of people outside the plant:

- external exposure due to the airborne beta oder gamma activity of the cloud,
- external exposure due to the gamma activity deposited on the ground,
- internal exposure following inhalation of radionuclides from the plume,
- internal exposure following inhalation of resuspended radionuclides,
- internal exposure due to ingestion of contaminated foodstuffs.

External exposure due to the cloud activity will be acute only during the time the cloud is passing. This will occur in the early phase of an accident. Due to the short range in air and the limited penetration the beta activity will cause a skin dose only and is usually negligible in comparison to other pathways.

External exposure due to activity deposited on the ground (on roads, buildings, roofs) is limited to gamma activity for the same reason as discussed above. The resulting dose will be reduced by radioactive decay and by natural removal processes as e.g. migration into soil.

Internal exposure following inhalation of radionuclides from the plume is a pathway arising from the passing time of the plume. This will result in an exposure over a longer time period depending mainly on the physical and biological half-life of the nuclide.

Internal exposure following inhalation of radionuclides resuspended from initially deposited radioactive material depends on the nature of the ground (smooth or rough, humid or dry), the deposit (particle size) and the atmosphere (turbulence class, wind velocity). This pathway can have importance if at all only in a late phase of an accident.

Internal exposures due to ingestion of foodstuffs contaminated by deposited activity can be important due to direct contamination and due to indirect contamination via transfer from soil to the foodstuff. This pathway may lead to an exposure of people living far away from the plant and from the contaminated area.

The relative importance of these different modes of exposure in the case of an accident depends on many boundary conditions:

- type of the accident,
- nuclide spectrum,
- chemical form of the nuclides,
- weather conditions during the accident,
- effectiveness of the countermeasures.

The consequences of the exposure may be somatic or hereditary, this means effects in the irradiated individual himself or in his descendants. The somatic effects may be either stochastic or nonstochastic. Nonstochastic effects can occur shortly after exposure to high levels of radiation and are those for which the severity of the effects varies with dose and for which a threshold may occur. Stochastic effects generally appear long after irradiation and are those for which the probability of the effect occuring, rather than its severity, is taken to be a function of dose without threshold.

A very important pathway in the case of an accident may be the acute exposure of the bone marrow in the early phase. In this case the value for the meadian lethal dose within 60 days ($LD_{50/60}$) is assumed to be in the range between 2.5 and 5 Gy with a lower threshold for this effect of about 1.5 Gy.

Health risks due to stochastic effects are described by risk factors. Due to ICRP the total risk factor for the incidence of fatal cancer is $1.25x10^{-2}$ Sv^{-1}.

Starting with this knowledge of effects it is possible to fix a set of dose limits for purposes of handling an emergency. These so-called emergency reference levels define something like the boundary to exclude nonstochastic effects and to keep the probability of stochastic effects at a reasonable low level.

3. PROTECTIVE MEASURES

The main purpose of emergency planning and enforcement is the reduction of radiological consequences to the public in the case of an accident.

Emergency protection measures are the necessary administrative supplement to the technical measures of engineered safeguards. The following overview will be made as general as possible. In those cases where special examples are given these examples have been taken, if not mentioned otherwise, from the emergency preparedness practice of the Federal Republic of Germany. Due to the general state of this paper it is not possible to describe the on-site emergency planning though this is a very important aspect for the effectiveness of emergency planning.

To get more detailed information about on-site and off-site emergency planning a lot of literature is available. To get the more general philosophy together with a lot of special aspects and information the following papers can be recommended (e.g. IAEA 81, IAEA 82a, IAEA 82b, BMI 77a, ICRP 84, EC 82).

Regarding this goal the responsible authorities have to handle a set of countermeasures:

- **Sheltering and respiratory protection**

  The public may be asked to stay in houses, close doors and windows and, if possible, move into shielded rooms, such as cellars. This will shield against external gamma radiation (depending on the wall thickness of the room) and reduce the inhalation of radioactive aerosols (depending on the frequency of air changes in the rooms).

- **Iodide tablets** (if release of radioiodine is taken into account)

  The internal radiation exposure mainly of the thyroid by radioiodine can be reduced by the consumption of iodide tablets due to a blocking effect. The efficiency of this radioprotective prophylaxis depends mainly on the time interval between iodide tablets intake and incorporation of radioiodine.

- **Evacuation**

  Evacuation can be an effective countermeasure if it can be carried out in time. But it should be mentioned that this protective measure has its own risks and will be very difficult if a large number of people has to be evacuated.

These countermeasures can be most effective in the early phase of an accident and most appropriate to reduce the number of early fatalities.

In accordance with these possibilities, and staggered by radiation doses in the open air, the measures indicated in Table 2 have been proposed by the German Advisory Committee on Radiation Protection (Strahlenschutzkommission).

These protective measures are partly prophylactic or they are at least able to reduce the consequence to a lower level. In each case the choice of the adequate countermeasure depends on some relevant boundary conditions of the specific accident sequence.

Introducing the acute emergency measures quoted in Table 2 involves a tremendous responsibility. This applies above all to evacuation. This step might create a panic among the public which is in no way justified by the true radiation hazard, and if conditions are adverse, these measures might even cause accidents. Neither consequence should be the result of precautionary measures, and it should be put up only if there is a really acute hazard to health or life. In the first instance, in order to provide the necessary technical information even for the unlikely case of a major release of radioactivity, the expert committee regarded it as its duty to pronounce general recommendations for the initiation of acute emergency measures. Naturally, such recommendations can be made only with the proviso that each specific case with all its ramifications should be considered. For this reason, no strict limits have been given for the initiation of specific measures; instead, it has been explained which acute emergency measures should be recommended in accordance with the guide levels indicated here. In specific cases different decisions will be justifiable or even necessary under special local conditions.

Dose in open air[1] (Sv)	Recommended measures	
	Stay in house[2]	Evacuation
< 0.25	useful	no
0.25 - 1	necessary	useful
> 1	necessary until evacuation	necessary

Irradiation of the whole body by external radiation and inhaled radionuclides.

Dose in open air[1] (Sv)	Recommended measures		
	Stay in house[3]	Iodide tablets[4]	Evacuation
< 0.25	useful	not necessary	no
0.25 - 5	necessary	useful, necessary when > 1 Sv	not necessary
> 5	necessary until evacuation	necessary even when evacuated	useful, necessary when > 10 Sv

Irradiation of the thyroid gland by inhaled radioiodine.

Comments

[1]) The dose levels indicated refer to short-term exposures (in hours or days) in the open air, independent of age or sex.

[2]) The dose reduction of external radiation if persons stay in their houses and seek shelter depends on the shielding provided by walls and ceilings. A factor of at least 5 may be expected for houses customary in FRG.

[3]) The dose reduction if persons stay in their houses and close their windows and doors depends above all on the changes of air in the respective rooms and on the meteorological distribution factors. A dose reduction by a factor of 2 may be expected for houses customary in FRG.

[4]) The dose reduction by the administration of iodide tablets is approximately 80% for adults exposed to radioiodine, if these tablets are taken within 2 hours following inhalation; the reduction is 50% if the tablets are administered within 6 hours.

Table 2: Emergency reference levels and recommended measures in case of emergency at a nuclear facility.

4. CLASSIFICATIONS

To prepare an effective emergency plan it is necessary to introduce some classifications to obtain an instrument one can handle in a practicable way. This especially will be important for the following aspects of the plan:

- emergency classification,
- alarm levels,
- alarm measures,
- emergency planning zones.

Emergency classification

There are different approaches to classify the emergency situations. IAEA for example recommends a system compatible with that used by many public authorities (IAEA 82b).

- Emergency Standby
  Appropriate plant personnel are placed on standby, i.e. they are alerted, in order to be in readiness for an emergency situation; appropriate off-site organizations may also be put on standby.

- Plant Emergency
  The consequences of the emergency situation are confined to a section of the plant. On-site personnel are activated and appropriate off-site organizations notified.

- Site Emergency
  The consequences of the emergency situation are confined to the site. The personnel on-site are activated and off-site organizations are notified. Some of the latter may be activated.

- Off-site Emergency
  The consequences of the emergency situation extend beyond the site boundary. The overall emergency plan is put into effect.

Alarm levels

Omitting in this paper the problems of on-site emergencies in the Federal Republic of Germany we have for the field of off-site emergencies introduced three alarm levels:

- Emergency alert
  Emergency alert is initiated in case of an accident in a nuclear facility which has not yet given rise to any or to major impacts on the environment below the criteria fixed for emergency alarm, but where the possibility of such impacts cannot be excluded with absolute certainty.

- Water alarm
  Water alarm is initiated after a hazardous release of radioactive substances only into bodies of water.

- Emergency alarm
  Emergency alarm is raised if an accident in the nuclear facility has given rise to a hazardous release of radioactive substances into the air or is likely to do so very soon.

Criteria for the operator to determine alarm levels

As a rule, alarm levels are initiated by the emergency protection staff following a recommendation by the operator. Due to a draft version of a recommendation of the Committee on Emergency Protection Measures the operator shall inform the emergency protection staff at the latest when at least one of the criteria set forth below is met:

- Criteria for emergency alert

  - General Criterion
    Sequences of events likely to be associated with releases of radioactive substances into the environment of the plant, which could give rise to a whole body dose of more than 0.05 Sv or a thyroid dose of more than 0.15 Sv in the environment of the plant.

  - Plant Criterion
    Sequences of events in the reactor, the occurrence of which prevents any further operation of the plant for safety reasons and in which the minimum number of safety systems required in the design to control such events are not fully effective.

    This criterion is presumed to be met, e.g., in the following plant states:

    - The core is cooled to an insufficient degree, i.e., the minimum conditions for observation of the emergency cooling criteria are not met.

    - The release of radioactive substances at levels above those indicated in column 3 of Table 3 is only prevented by one design basis barrier fully functioning.

  - Emission Criterion
    Release of airborne radioactive substances into the environment in such a way that 1/10 of the release levels indicated in Table 3 was found to have been exceeded.

- Criteria for emergency alarm

  - General Criterion
    Sequences of events in which releases of radioactive substances into the environment of a plant either were ascertained or are likely to occur, which can give rise to a whole body dose and an effective dose, respectively, in the environment of the plant in excess of 0.05 Sv or a thyroid dose in excess of 0.15 Sv.

  - Plant Criterion
    Sequences of events in the reactor, the occurrence of which prevents any further operation of the plant for

safety reasons and in which the minimum number of safety systems required in the design to control such events are not fully effective and the effectiveness of the retention systems provided (barriers) is either considerably impaired or in direct danger of being lost.

This criterion is presumed to be met, e.g., in the following plant states:

- The core has been damaged because of insufficient cooling. Sufficient cooling of the core continues to be impossible.
- A release of radioactive substances at levels above those indicated in column 3 of Table 3 is only prevented by one design basis barrier which, however, is in direct danger of being lost.

- Emission Criterion
  Release of airborne radioactive substances into the environment in such a way that the release levels listed in Table 3 either were found to have been exceeded or are presumed to be exceeded in the near future.

Nuclide group	Organ exposed	Release levels (Bq) Emission heights 50 - 80 m	81 - 130 m	131 - 150 m
Noble gases	Whole body	$5x10^{16}$	$1x10^{17}$	$2x10^{17}$
Cesium		$1x10^{15}$	$1x10^{15}$	$2x10^{15}$
Other nuclides		$4x10^{15}$	$1x10^{16}$	$1x10^{16}$
Iodine	Thyroid	$7x10^{12}$	$2x10^{13}$	$6x10^{13}$

Table 3: Activity release corresponding to a whole body dose of 0.05 Sv and a thyroid dose of 0.15 Sv.

Table 3 contains release levels resulting in a potential radiation exposure of 0.05 Sv as a whole body dose and 0.15 Sv as a thyroid dose at the most adverse point of impact. The release levels are indicated for various effective stack heights and for four groups of nuclides. The selection of nuclide groups is based on the stack instrumentation customary in nuclear power plants. A summation formula must be applied if several nuclide groups are released.

The wind speed has been assumed to be 1 m/s at 10 m above the average disturbance level. For wind speeds $\geq$ 2 m/s, the release levels indicated in the table may be multiplied by the amount of the wind speed. For release times in excess of 8 h, the release data according to the table may be multiplied by a factor of 2.

The release levels in the table are based on the following assumptions:

- Radiation exposures have been calculated in accordance with the basic principles of accident calculation in the Federal Republic of Germany with an integration period of 50 a for the whole body and for the thyroid.

- For the ground radiation, ingestion and inhalation exposure pathways, the values have been determined on the basis of statistical evaluations of real weather records collected at a selected site.

- Cloud radiation is determined by the envelope of the curves of all diffusion categories A to F.

- For the ingestion exposure pathway, an intake of contaminated food has been assumed up until 24 h after the onset of the release.

- The period for which the population is exposed unshielded to radiation from the radionuclides deposited on the ground has been assumed to be seven days.

Alarm measures

Starting with the alarm levels one can define three classes of alarm measures with partly different details applying them to the three alarm levels:

- Stage 1 alarm measures include the alarms to be initiated upon receipt of an alarm signal by the emergency protection staff and the necessary preparations for further measures which must be taken right away and without special instructions at each alarm level.

- Stage 2 alarm measures serve for the protection against acute dangers. They can be taken only by special decision made in the light of more detailed knowledge of the nuclear accident and the first results of examinations.

- Stage 3 alarm measures shall follow and serve for the elimination of dangers that do still exist. They shall be subject to the special conditions of the emergency. These measures shall also be planned in advance to enable a rapid and efficient execution.

Following one can find details of these alarm measures provided for the three alarm levels taken from german regulations (BMI 77a).

Allocation of Alarm Measures to Alarm Levels

Measures in the case of emergency alert

- Class 1 emergency measures:
  - Alarming of the authorities in charge.
  - Gathering of the emergency protection staff in minimum strength, including the licensee's expert.
  - Stand-by readiness of the other members of the emergency protection staff and the measuring services.
  - Preparation of the measuring equipment.
  - Notification of neighbouring administrative authorities if these may get involved.

- Class 2 and 3 emergency measures, which will affect the population, are not required in an emergency alert.

Measures in the case of water alarm

- Class 1 emergency measures:
  - Alarming of the authorities and offices in charge.
  - Gathering of the emergency protection staff.
  - Action of measuring services for measurements of radioactivity in water and sludge, if required.
  - Notification of neighbouring administrative authorities if these may get involved.

- Class 2 emergency measures:
  - As required - warning to downriver water supply points.
  - As required - warning to the downriver population not to use the water and refrain from water sports and fishing.
  - As required - notification or restriction of shipping.

- Class 3 emergency measures:
  - Closing of contaminated water supply points and of heavily contaminated areas.
  - Decontamination of personnel, incorporation measurements and decorporation.
  - Medical care and, if necessary, treatment of personnel.
  - Decontamination of animals and/or removal of heavily contaminated animals.
  - Assurance of water supplies and, if required, decontamination of the water supply system.

Measures in the case of emergency alarm

- Class 1 emergency measures:
  - Alarming of the authorities and emergency services in charge.
  - Gathering of the emergency protection staff.
  - Definition of the endangered area on the basis of zones and sectors.
  - Action of measuring services; measurements to be taken according to a special plan.
  - Notification of neighbouring administrative authorities if these may get involved.

- Class 2 emergency measures:
  - Information of the population according to a prepared text by means of public address cars, including, if necessary, the announcement that iodine tablets will be distributed. If a large area has to be informed the facilities of the emergency services (sirens) shall be used and supplemented by special broadcast and television announcements.
  - Traffic restrictions according to a prepared plan.
  - As required - distribution of iodine tablets.
  - As required - evacuation according to a prepared plan.
  - As required - transportation and housing of persons who have been overexposed to radiation.
  - As required - warning to downriver water supply points and to the downriver population not to use the water and refrain from water sports and fishing.

- Class 3 emergency measures:
  - Closing of contaminated water supply points and of heavily contaminated areas.
  - Decontamination of personnel, incorporation measurements and decorporation.
  - Medical care and, if necessary, treatment of personnel concerned.
  - Supply of uncontaminated food to the population and of uncontaminated fodder to animals.
  - Confiscation of contaminated food and fodder, if possible, subsequent decontamination.
  - Decontamination of animals and/or removal of heavily contaminated animals; evacuation in special cases.
  - Assurance of water supplies and, if required, decontamination of the water supply system.

Emergency planning zones

For a better handling of emergency planning and implementation of emergency measures it is useful to classify the environment of the nuclear facility to get so-called emergency planning zones. The details of these classifications are very different in different countries. Therefore as an example the practice in the Federal Republic of Germany shall be described here.

The environment of a nuclear facility is broken down into the following zones for the purpose of defining preparatory measures:

- Central zone
  The central zone directly surrounds the nuclear facility. Its boundaries are a function of local conditions (size of plant, site structure). Only in exceptional cases will its radius exceed 2 km.

- Median zone
  The median zone surrounds the central zone. Its outer limits are fixed by a circle with a radius of up to approximately 10 km.

- Outer zone
  The outer zone surrounds the median zone. Its outer limits are fixed by a circle with a radius of up to approximately 25 km.

The median zone and the outer zone are subdivided into sectors of 30° or 22.5°, which sectors are numbered consecutively in a clockwise direction, starting in the north.

For the central zone and the median zone the necessary alarm measures must have been prepared. In the outer zone it is only necessary to determine the measuring and sampling stations and prepare for alerting. Outside the outer zone there is generally no need for preparatory measures.

5. ORGANIZATION

It is obvious that the emergency planning and in particular the implementation of emergency measures will only work having a well defined and trained organization. An essential precondition will be that there are no ambiguities regarding the responsibilities of the different organizations involved. In addition it is necessary that the emergency plans of the involved organizations are coordinated efficiently and, if possible, exercised.

In practice the approaches in the different countries differ to a large extent due to legal requirements, organizational structures and available technical possibilities. Therefore the principal aspects will be discussed again giving an example from the Federal Republic of Germany.

In the Federal Republic of Germany, the federal states are responsible for the organization and implementation of emergency control. However, in an attempt to harmonize the local emergency plans to be established by the licensee and the authorities the regulatory authorities of the federal states and the Federal Ministry of the Interior have issued recommendations for the planning of emergency control measures by the authority (BMI 77a) and by the licensee (BMI 77b).

The responsibilities must be distinguished into on-site and off-site aspects:

- on-site responsibility: licensee

  As the operator has all the information to judge the situation of the facility the shift on duty is in the position to make the initial assessment of the accident and the possible consequences for the environment. Therefore the main tasks of the operator will be:

  - Assessing the actual accident situation and predicting the resulting conditions relevant for off-site consequences.

    These questions can be answered only by the operator because they demand information about the present status of the plant, the efficiency of the safety features, the consequences of malfunctions, possible activity release and release pathways etc.

  - Measuring the atmospheric dispersion conditions relevant for the off-site consequences.

  - Predicting the potential radiation exposure in the vicinity of the plant to give the first informations to the emergency protection staff of the authorities.

  - Assisting the responsible authorities by sending an expert to work together with authorities in the emergency operating control center.

- off-site responsibility: authorities

  The main purpose of the responsible authorities in the case of an accident is:

  - independent assessments of the possible off-site radiological consequences,

- selection of the most adequate emergency measure for the different regions and time phases,
- initiating and implementation of all protective action off-site:

  - alarming,
  - assigning of measuring teams,
  - measurements,
  - information of the public,
  - traffic control,
  - distribution of iodide tablets,
  - evacuation.

6. MEASUREMENTS

During an accident the emergency protection staff needs a lot of information to be in a position for choosing the adequate countermeasures in each phase. These informations have to come from the nuclear installation and from the off-site environment.

The plant operator should provide especially the following information:

- amount of radioactivity released,
- nuclide vector of radioactivity released (at least amounts of the relevant groups),
- time characteristic of release (probable beginning and duration),
- point of release,
- wind direction, wind speed, diffusion category, precipitation rate,
- operational status of engineered safety features.

These informations should result, if possible, from direct measurements or from estimations on the basis of indirect measurements. To assure that the main informations can be provided during an accident the corresponding equipment should be designed so that it can work and be read even under severe accident conditions regarding the local environment (temperature, pressure, humidity, radiation) and the range of the measured values.

Measurements to be taken off-site and required in order to allow the consequences of a nuclear accident to be judged are of the following types:

(a) dose rate measurement (gamma radiation),

(b) determination of the concentration and type of airborne radioactive substances,

(c) determination of the content of radioactive substances in vegetation,

(d) determination of the content of radioactive substances by direct measurement of contamination,

(e) determination of the radioactivity concentration in fresh milk of cows grazing in the area concerned,

(f) determination of the radioactivity concentration in surface water.

Measurements under (a) and (d) above should generally be carried out with portable equipment in the field. The other measurements require sampling at representative points followed by measurements in a special laboratory.

In general, measurements under (a) and (b) will enjoy priority. Measurements under (c) and (d) are also required within the first few hours after a nuclear accident in order to allow the situation to be assessed. Radiation detection squads of the police, the fire brigade or of general emergency protection services should be charged only with measurements under (a) and samplings under (b) and (c). All other measurements and samplings should be carried out by expert measuring organizations.

All measurements discussed before will be useful in the case that release of radionuclides due to an accident has already happened. But as one could see looking for the different types of countermeasures the protective actions necessary in the early phase of an accident will be most successful when there is time enough to initiate and perform these actions. For this reason the most important information should come from measurements inside the plant which can give useful hints for the future development of an accident especially regarding the release of radioactive material. This has to be done by interpreting the measurement of e.g. pressure, temperature and activity of primary coolant or containment atmosphere. Important in this frame will not only be the momentary state but the anticipated development with time. Most relevant for a prognosis of radioactive releases will be the state of the different barriers, especially of the containment. Based on these information and having additional measurements as discussed before it should be possible to give a prognose of radiological consequences off-site and to initiate the proper countermeasures in time.

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ENVIRONMENTAL MONITORING OF NUCLEAR FACILITIES

- a contribution to environmental safety and public acceptance of nuclear activities -

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1. INTRODUCTION

Nuclear facilities, such as nuclear power plants, research reactors, fuel element fabrication plants, radioactive waste repositories or reprocessing plants, discharge residues of radioactive substances into their respective environments. The radiation emitted by those radioactive substances may cause man to be exposed to external or internal radiation.

The radioactive emissions of nuclear facilities constitute part of the manmade radiation exposure of the public which, however, results mainly from the application of X-rays and sources of ionizing radiation for diagnostic and therapeutic purposes in medicine and from the fallout of nuclear weapon tests carried out above ground. The sum total of all contributions to manmade radiation exposure is approximately 0.6 mSv/a in terms of genetically significant dose for the average of the population in the Federal Republic of Germany. The contribution from nuclear facilities to the overall manmade radiation exposure is less than 1 µSv/a.

2. OBJECTIVES OF ENVIRONMENTAL MONITORING

Environmental monitoring of nuclear facilties, i.e., monitoring for potential repercussions on its immediate vicinity of the operation of a nuclear facility, is part of general monitoring for environmental radioactivity all over the territory of the Federal Republic of Germany. The interest in environmental monitoring is limited to watching for the occurrence of manmade radioactive substances and the external and internal radiation exposure these may cause to the public living in the immediate vicinity of a specific nuclear facility. Radioecological studies and large area environmental monitoring for manmade radioactivity, especially with regard to pollution superimposing in areas with several nuclear facilities, must be left to governmental or scientific institutions as a more demanding job. Problems of this type are solved in particular by the eight "Leitstellen" (control centers) for monitoring environmental radioactivity.

Environmental monitoring supplements the control of emissions of radioactive substances from nuclear facilities. The basis of emission control is found in Section 46 of the Radiation Protection Ordinance (1). The type and scope of emission control in light water cooled reactors is described in the pertinent rules drafted by the Kerntechnischer Ausschuß (Nuclear Technology Committee) (2, 3). The radioactive substances discharged with liquid and gaseous effluents give rise to certain pollution levels in the immediate environment. It is one of the main duties of environmental monitoring, therefore, to detect manmade radioactivity in various media constituting relevant exposure pathways and to measure directly the external radiation exposure of the public in the environment. In this way, on the basis of known emission data and meteorological and hydrological diffusion parameters, the radiation exposure in the environment is calculated by means of radioecological models. As a result of the variances in parameters and statistical quantities mentioned above, all radioecological computer models contain a number of so-called conservative assumptions, i.e., unfavorable assumptions or safety factors with respect to computed annual radiation doses.

As a consequence, practical environmental monitoring has its significance not only in demonstrating that prescribed dose limits are observed, but also in indicating, by measurements, the gap between conservative estimates and environmental exposures which, in all experience, are much lower.

For practical environmental monitoring of nuclear facilities, three sets of problems can be formulated:

(1) Assessment, by so-called background measurements, of the environmental radioactivity existing before commissioning of the respective nuclear facility.

(2) Routine monitoring of the environment of a nuclear facility, while that plant is operated according to permit.

(3) Environmental monitoring for accidental releases of radioactive substances.

Background measurements are to assess diffusion patterns of radioactivity in the environment which may be due to a specific site. Such "stocktaking" of environmental radioactivity is to allow, during subsequent operation of a nuclear facility, to distinguish pollutions due to plant operation from background activity and background dose rates, respectively.

Routine monitoring serves for continuous control of the observation of set limits, its purpose is the complete and quantitative assessment of all pollution as far as possible. In-house monitoring by the operator of a nuclear facility may be restricted to the area of the plant site and its immediate environment.

Practical environmental monitoring is particularly important in cases of undiscovered escapes of radioactive substances or accidental radioactivity relreases. In such instances, it serves to determine the type, intensity and extension of potential environmental contamination by direct measurements in situ and by analyses of representative samples. In this connection, it is important that measured data are made available to the action teams as quickly as possible as a basis for decision making. The emergency measures initiated by the operator tie in with an accident monitoring program organized by government agencies.

3. IMPLEMENTING ENVIRONMENTAL MONITORING

3.1 Conditions

A number of indispensable preconditions must exist for environmental monitoring to be performed effectively. The type and number of constant and potential emitters must be known. The results measured in emission monitoring must always be made available in the shortest possible period of time. Besides radioactivity concentration data this also includes information about gaseous and liquid effluent volumes and records of different operating conditions of the nuclear facility in question.

Another important precondition is the exact knowledge of a number of general factors about the environment. Such factors of interest include the topography of the terrain, plant growth and building structures, settlement patterns, typical agricultural products, volumes of crops, locations and sizes of agricultural areas.

A factor of particular importance in this connection is the microclimate in the immediate vicinity of a nuclear facility. Statistically backed meteorological data on the site and a minimum of information continuously available about present weather conditions are necessary for assessment of the atmospheric diffusion of the radioactive substances emitted with gaseous effluents.

3.2 Aspects in Drawing Up Monitoring Programs

General principles of environmental monitoring were formulated by the ICRP (International Committee on Radiological Protection) as early as in 1965 (4). Basic principles of environmental monitoring were adopted by the Commission of the European Communities (5).

Schematic diagrams of potential transmission pathways of radioactive substances emitted by nuclear facilities into air and water as the transport media are shown in Figures 1 and 2. Experience and numerous studies have shown that specific nuclides and specific exposure pathways are of greater importance than others in causing radiation exposure of the public. Such nuclides and exposure pathways are called "critical." The group of the population in the environment of a nuclear facility, which must be regarded as being potentially exposed to radiation, is called the "critical" group of the population. Taking into account such "critical" quantities is recommended both in establishing routine programs and in selecting monitoring measures for accident situations.

In setting up a monitoring program, also those provisions and rules must be observed in addition to the monitoring goals and preconditions mentioned above, which are contained in the Radiation Protection Ordinance or in special conditions imposed by the responsible supervisory authorities.

3.3 Regulations and Dose Limits in Environmental Monitoring Under the German Radiation Protection Ordinance

The basic requirements of organization and practical implementation of environmental monitoring in nuclear facilities can be derived from the sections in the Radiation Protection Ordinance (1) dealing with the "protection of the public and the environment from the hazards of ionizing radiation" and with the definition of "radiation protection areas." The provisions formulated in those sections indicate a system of various physical monitoring areas, for which different dose limits were defined.

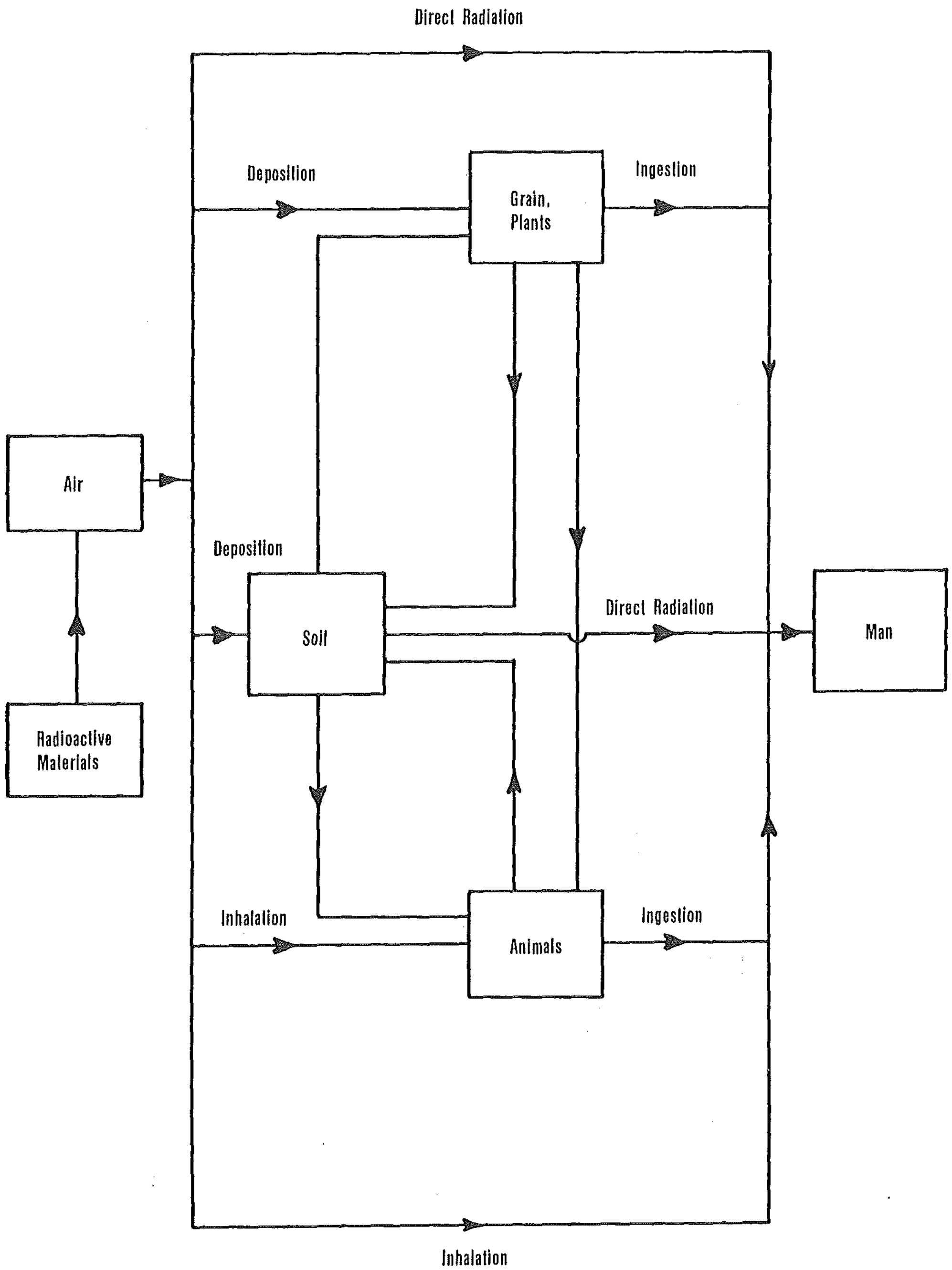


Fig. 1: Schematic diagram of the transmission pathways from radioactive substances discharged into the atmosphere to man.

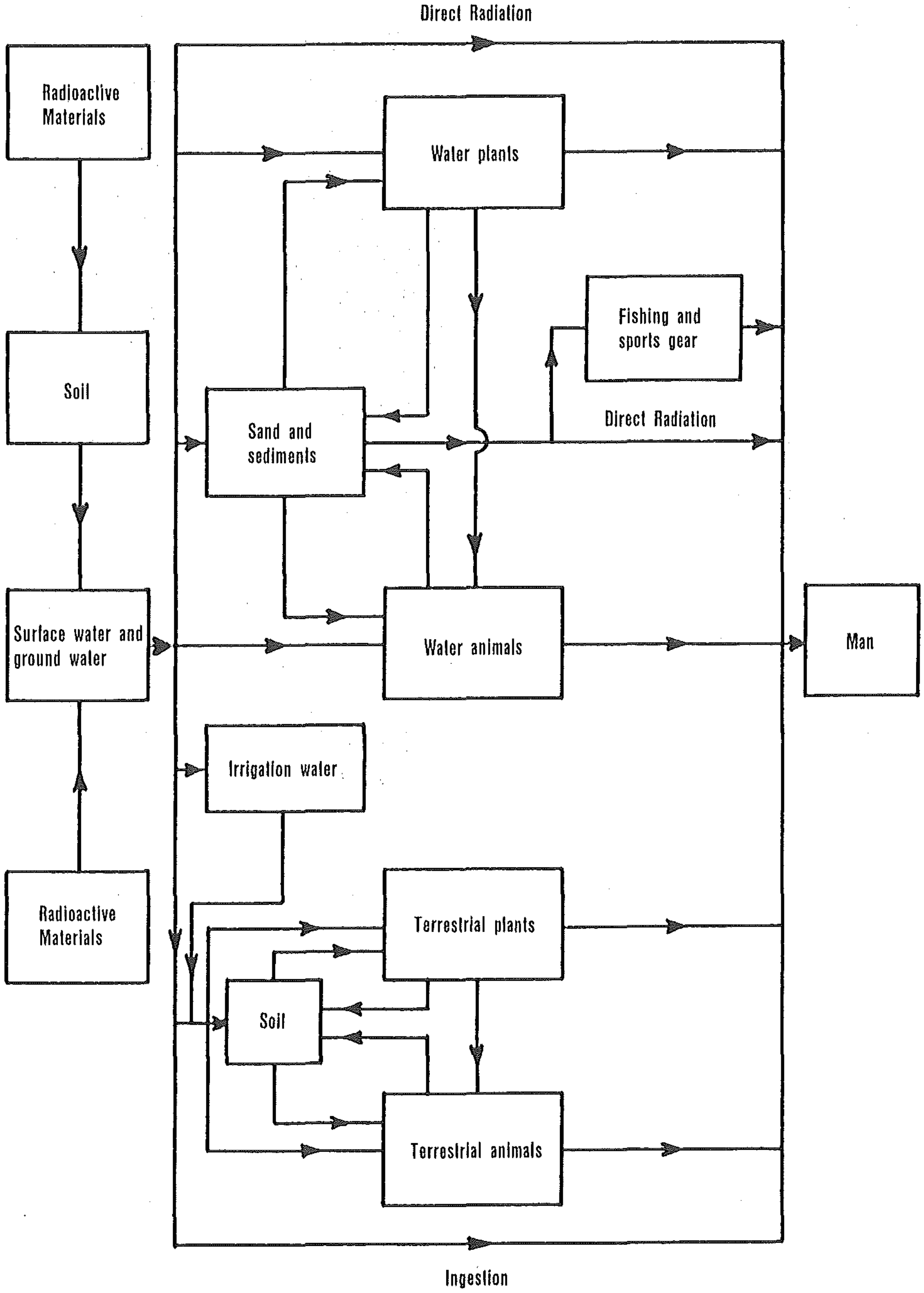


Fig. 2: Schematic diagram of the transmission pathways from radioactive substances discharged into ground or surface waters to man.

The "areas, which are not radiation protection areas" practically mean the national territory at large. Section 45 of the Radiation Protection Ordinance requires that the technical design and operation of a nuclear facility be planned in such a way as to minimize the radiation exposure of persons due to radioactive substances discharged from the plant together with the gaseous or liquid effluents. Such radiation exposure must not exceed specific limits for various areas of the human body (see Table 1). In calculating radiation exposures, the "most adverse points of impact, taking into account all relevant exposure pathways, including the food chains," shall be used as a basis. It is also important to know that the dose limits should not be regarded as limits per plant, but refer to the Federal Republic of Germany. This is to say that they must also be observed by overlapping pollution levels coming from more than one plant or site.

	Body area	Dose limits mSv/a
1.	Whole body, bone marrow, gonads, uterus	0.3
2.	Hands, forearms, feet, lower legs, ankles, including the skin of those parts	3.6
3.	Skin, if only the skin is exposed to radiation, except for the skin of the hands, forearms, feet, lower legs and ankles	1.8
4.	Bone	1.8
5.	Thyroid and other organs	0.9

Table 1: Maximum permissible radiation exposures in the environment of nuclear facilities caused by discharges of radioactive substances with the gaseous or liquid effluents.

4. GUIDELINE FOR IMMISSION MONITORING OF NUCLEAR FACILITIES IN THE FEDERAL REPUBLIC OF GERMANY

In 1974, the German Bundesgesundheitsamt (Federal Health Office) jointly with a number of other institutions drafted "Guidelines for Measures of Monitoring the Environment of Nuclear Power Plants Incorporating Light Water Cooled Reactors" for the Federal Republic of Germany. Those guidelines helped to standardize environmental monitoring programs and make their results capable of comparison. A revised guideline was published in November 1979 by the Federal Ministry of the Interior, entitled "Emission and Immission Monitoring of Nuclear Facilities" (6).

4.1 Principles

Monitoring of impacts in the environment of nuclear facilities is a supplement of emission monitoring. The results are necessary for preservation of testimony, for control of radiation exposure calculated from the results of emission monitoring and for taking precautions with respect to possible incidents.

In case of releases due to an incident appropriate sampling and measurements in the environment are to provide a quick survey of a situation, so as to furnish arguments for decisions at an early stage. In this context, measurements shall be made in the possible areas of impact.

Two monitoring programs in principle must be established for environmental monitoring of nuclear facilities:

- a program to be implemented by the operator of a facility, and
- a supplementary and controlling program to be implemented by the measuring service charged by the authority.

To be able to record any future impacts of nuclear power station operation and possible preliminary burden and for training implementation of major parts of this program must start at least two years prior to plant commissioning.

4.2 Monitoring Programs for Licensees and Independent Measuring Organizations

The licensee's sampling and measuring points shall cover in particular the immediate vicinity of the nuclear power plant and the monitoring of the transport media water and air as far as the deposition on the ground, vegetation and sediment in such vicinity. Therefore, measurements shall be carried out and samples taken predominantly in the area of the most unfavorable point of impact for water and air considering the prevailing diffusion conditions.

The sampling and measuring points of the independent measuring organization exceed the licensee's sampling and measuring network insofar as food chains on land and in water are included for monitoring purposes. The program of the measuring organization should be oriented more to the utilization of the environment of the nuclear power plant by the population. It shall ensure a verification of the data measured by the licensee and, at the same time, supplement his measuring program.

4.2 Exposure Pathways

The following exposure pathways must be taken into account when setting up the environmental monitoring programs:

external radiation exposure:

- beta submersion
- gamma submersion
- soil radiation

internal radiation exposure:

- inhalation of radionuclides
- ingestion of radionuclides by the uptake of
  - oo drinking water
  - oo plant products (for instance green vegetable, grain)
  - oo animal products (for instance meat, fish, milk).

4.4 Media and Radionuclides to be Monitored

Measuring of the air (monitoring of direct radiation and airborne activities) shall include, in each case, monitoring of the exposure pathways of gamma submersion, ground radiation and inhalation. In general, beta submersion need not be monitored, however, the respective necessity shall be examined upon the merits of each case considering the relevance of this pathway.

The monitoring of water shall include the monitoring of the activity concentration in the water and in the sediment. In general, the exposure pathways of gamma submersion and beta submersion need not be monitored, however, the respective necessity shall be examined upon the merits of each case considering the relevance of these pathways.

The following criteria shall be used in the monitoring of the exposure pathway of ingestion:

- The monitored medium should be as close as possible to the end of the food chain, i.e., it should preferably be a foodstuff.

- The monitored foodstuff should be typical of the nuclear facility site environment.

- The monitored foodstuff should suggest a significant contribution to the entire ingestion dose.

The plant products to be monitored should be chosen so as to possibly cover diverse products which become ready for harvesting at different times of the year, in this context, preference should be given to plants whose overground parts are destined for human consumption.

Since the relative contribution of radionuclides occurring to the total activity emitted may differ for the individual facilities, the selection of the radionuclides to be monitored shall be adapted to the expected and actual radionuclide mixture, respectively, occurring in the nuclear facility.

4.5 Sampling and Measuring Methods, Locations and Frequencies

Suitable sampling and measuring methods are described inter alia in "Meßanleitungen für die Überwachung der Radioaktivität in der Umgebung von Kernkraftwerken und sonstigen kerntechnischen Anlagen" (Measuring Instructions for Monitoring the Radioactivity in the Vicinity of Nuclear Power Stations and Other Nuclear Facilities), elaborated by the central offices for monitoring of the environmental radioactivity, as well as in the loose-leaf edition issued by the Working Group "Umweltüberwachung" (Environmental Monitoring) of "Fachverband für Strahlenschutz".

Sampling and measuring locations must be specified in the environment of the nuclear power station. They shall be located in an area where a measurable impact by the facility is possible.

The sampling and measuring locations shall be located preferable in the area of the point of impact least favorable with respect to the individual exposure pathways.

The network of the sampling and measuring locations shall include points which are largely unaffected by nuclear facilities (reference areas).

Within the framework of precautions against accidents measuring and sampling locations shall be provided above all near the communities situated in the immediate vicinity.

The number of sampling and measuring locations is specific of the site. It shall be seen in the context of the sampling and measuring frequencies and shall be fixed as a function of the media to be monitored. For the purpose of optimization of the evidence of measurements priority shall be given to a meaningful selection of the sampling and measuring locations instead of too a high number of such locations.

To be able to perform quick and specific samplings and measurements during accidents, the number of sampling and measuring locations shall be fixed taking into account the structure of settlement and the existing disaster control plans.

The sampling and measuring frequencies and, in case of continuous sampling, the duration of the period of collection, respectively, shall be adapted to the physical half-life and to the time of radionuclide transfer to man.

If an exposure pathway is interrupted during specified periods of the year (for instance changeover from green fodder to dried fodder) sampling can be abandoned during this period.

4.6 Detection Limits

To guarantee by environmental monitoring an additional control of observance of the dose limits as stipulated in § 44 and 45 of the Radiation Protection Ordinance, one third in total of the respective dose limit shall be detectable, i.e. for instance 0.1 mSv/a of the whole body dose via exhaust air and liquid effluents and 0.3 mSv/a of the thyroid dose via ingestion.

In the measurement of single-nuclide activity in air, drinking water and foodstuffs the major radionuclides in terms of radiation exposure shall be recorded with a detection limit corresponding to 1/30 of the dose limits, i.e. for instance 10 µSv/a in case of the whole body dose and 30 µSv/a in case of the thyroid dose by ingestion. Since experience has shown that only few nuclides make significant contributions to radiation exposure on every exposure pathway, it can be guaranteed that 1/3 in total of the respective dose limit can be detected.

When comparing the detection limits achievable with the requirements stated above the following aspects shall be taken into account:

- By measurement of the local dose at the fence of the nuclear facility a whole body dose of 0.5 mSv per year caused by external gamma radiation should be detectable.

- By measurement of the local dose in the environment a whole body dose of 0.1 mSv per year caused by exhaust air and liquid effluents should be detectable.

- If in the activity measurement of single nuclides detection limits are attained which correspond to a dose much lower than 1/30 of the respective dose limit, reduction of the expenditure of measurement might be considered.

- If in the absence of additional expenditure in terms of measurement detection limits can be achieved which correspond to a dose much lower than 1/30 of the respective dose limit this particular method shall be preferred.

- Detection limits for single nuclides corresponding to a dose of more than 1/30 of the respective dose limit are acceptable in the individual case, provided that 1/3 of the respected dose limit can be detected for the total exposure. Otherwise, either more sensitive methods shall be employed or other media monitored for which more sensitive methods are available.

4.7 Measurements during Incidents

The licensee and the independent measuring organization shall have available and test measuring and evaluation methods to be applied during incidents and enabling rapid statements. The necessary measurements shall be practiced by way of the monthly measuring trips of the licensee and the semi-annual measuring trips of the independent measuring organization to the sampling and measuring points which have been laid down. The stationary facilities for continuous sampling and measuring shall be equipped in such a way that the measured data can also be used for assessment purposes during incidents.

In the event of incident-related releases of radioactive substances, the licensee and the independent measuring organization shall first perform random sample measurements in the potential hazard areas on the basis of the incident program. Additional monitoring measures during incidents will depend on the merits of each case.

5. ENVIRONMENTAL MONITORING PROGRAM FOR A NUCLEAR POWER PLANT IN THE FEDERAL REPUBLIC OF GERMANY

The measures to be taken in the Federal Republic of Germany by the licensee of the nuclear power plant and the independent measuring organization are compiled in Tables 2 and 3. The map following Table 3 shows the actual site map of the measurement and sampling locations for environmental monitoring of the Karlsruhe Nuclear Research Center. Figure 3 shows a fictitious site of a nuclear power plant and the sampling and measuring stations of the monitoring program.

Program item	Monitored medium and monitored type of radiation, respectively	Measured variables	Required detection limit	Sampling and measuring locations, respectively	Type and frequency of samplings and measurements	Remarks
1.	AIR					
1.1	γ-radiation	Local γ-dose rate	40 mSv/h	1 measuring location each in the area of the least favorable point of impact and in the diffusion direction, second in frequency	Continuous direct measurement	
1.2	γ-radiation	Local γ-dose	0.5 mSv/a	10 solid-state dosimeters at the fence of the plant	Annual evaluation	
1.3	Aerosols	a) Long-lived β-gross activity	1.8 mBq/m³ related to Sr-90	1 sampling location each in the area of the least favorable point of impact and in the diffusion direction, second in frequency	a) Continuous collection within a period of 14 days and evaluation every fortnight	a) Evaluation in the earlier 5 days after completion of sampling
		b) Specific activity of single nuclides determined by γ-spectrometry	0.37 mBq/m³ related to Co-60	1 sampling location each in the area of the least favorable point of impact and in the diffusion direction, second in frequency	b) Quarterly evaluation of a mixed sample	b) The mixed sample is to be composed from filters changed every fortnight
		c) Sr-90 activity concentration	1.8 mBq/m³	1 sampling location each in the area of the least favorable point of impact and in the diffusion direction, second in frequency	c) Quarterly evaluation of a mixed sample	c) The mixed sample is to be composed from filters changed every fortnight
		d) α-gross activity	3.7 mBq/m³ related to Pu-239	1 sampling location each in the area of the least favorable point of impact and in the diffusion direction, second in frequency	d) Quarterly evaluation of a mixed sample	d) The mixed sample is to be composed from filters changed every fortnight
1.4	Gaseous iodine	Specific I-131 activity	3.7 mBq/m³	1 sampling location each in the area of the least favorable point of impact and in the diffusion direction, second in frequency	Continuous collection within a period of 14 days and evaluation every fortnight	Evaluation as far as possible short-term after completion of sampling

Table 2: Environmental monitoring of a NPP by the operator. Program for normal operation.

Program item	Monitored medium and monitored type of radiation, respectively	Measured variables	Required detection limit	Sampling and measuring locations, respectively	Type and frequency of samplings and measurements	Remarks
2.	SOIL AND PLANTS					
2.1	Soil	a) Specific Sr-90 activity	74 mBq/kg related to dry matter	a) 1 sampling location in the area of the least favorable point of impact and at a reference area	a) 2 random samples per year	a) Soil and grass sampling at the same place and time
		b) Specific activity of single nuclides by γ-spectrometry	0.37 Bq/kg related to Co-60 and dry matter	b) 1 sampling location in the area of the least favorable point of impact and at a reference area	b) 2 random samples per year	b) Soil and grass sampling at the same place and time
2.1	Grass	Specific activity of single nuclides by γ-spectrometry	0.74 Bq/kg related to Co-60 and dry matter	1 sampling location in the area of the least favorable point of impact and at a reference area	2 random samples per year prior to the first and second hay harvest	Soil and grass sampling at the same place and time
3.	WATER					
3.1	Surface water	a) Tritium activity		a) 1 sampling location each in the inlet and the outlet building	a) Continuous sampling and quarterly evaluation	
		b) Residual β-activity	0.11 Bq/l related to K-40	b) 1 sampling location each in the inlet and the outlet building	b) Continuous sampling and quarterly evaluation	b) If residual β-activity > 0.37 Bq/l then measurement according to 3.1.c
		c) Specific activity of single nuclides by γ-spectrometry	74 mBq/l related to Co-60	c) 1 sampling location each in the inlet and the outlet building	c) Continuous sampling and quarterly evaluation	
3.2	Sediment	Specific activity of single nuclides by γ-spectrometry	18.5 Bq/kg related to Co-60 and dry matter	1 sampling location each in the inlet and the outlet building and in the area of the point of impact least favorable under consideration of the special site specific hydrological conditions	Quarterly evaluation of random samples	In the area of dams, tidal waters and fields of beans, the sampling locations have to be separately stipulated
3.3	Ground water	Specific activity of single nuclides determined by γ-spectrometry or residual β-activity	74 mBq/l related to Co-60 0.11 Bq/l related to K-40		Quarterly sampling of random samples and evaluation	If only residual β-activity is measured γ-spectrometry is required if activity > 0.37 Bq/l

Table 2: cont. Environmental monitoring of a NPP by the operator. Program for normal operation.

Program item	Monitored medium and monitored type of radiation, respectively	Measured variables	Required detection limit	Sampling and measuring locations, respectively	Type and frequency of samplings and measurements	Remarks
4.	AIR AND SOIL					
4.1	γ-radiation	Local γ-dose	0.5 mSv/a	40 solid-state dosimeters distributed according to the site specific conditions in the vicinity of the plant	Annual evaluation	Background γ-dose of natural origin approx. 0.8 mSv/a
4.2	γ-radiation	Local γ-dose rate	0.1 μSv/h	Monthly changing measuring locations at the selected locations in the zones and sectors of the environment of the plant	Monthly short-term measurements	Measures at the periodical measuring travel
4.3	Aerosols	β-gross activity	3.7 Bq/m^3 related to Sr-90	Monthly changing measuring locations at the selected locations in the zones and sectors of the environment of the plant	Monthly random samples and evaluation in the measuring car	Measures at the periodical measuring travel
4.4	Gaseous iodine	Specific I-131 activity	3.7 Bq/m^3 related to I-131	Monthly changing measuring locations at the selected locations in the zones and sectors of the environment of the plant	Monthly random samples and evaluation in the measuring car	Measures at the periodical measuring travel
4.5	Soil surface	β-gross activity	3.7 kBq/m^2 related to K-40	Monthly changing measuring locations at the selected locations in the zones and sectors of the environment of the plant	Monthly short-term measurements	Measures at the periodical measuring travel

Table 2: cont. Environmental monitoring of a NPP by the operator. Program for accidents.

Program item	Monitored medium and monitored type of radiation, respectively	Measured variables	Required detection limit	Sampling and measuring locations, respectively	Type and frequency of samplings and measurements	Remarks
1.	AIR					
1.1	Aerosols	Specific activity of single nuclides determined by γ-spectrometry	0.37 mBq/m³ related to Co-60	From the individual samples of the operator the Measuring Service charged by the authority makes mixed samples quarterly	Quarterly evaluation of mixed samples	
1.2	γ-radiation	Local γ-dose	0.5 mSv/a	10 solid-state dosimeters distributed at the fence of the plant	Annual evaluation	
2.	FOOD CHAINS IN THE COUNTRY					
2.1	Cow's milk	a) Sr-90 activity	18.5 mBq/l	a) Sampling at a farm with milch cows in the area of the least favorable point of impact and at a dairy	a) Twice a year during the period of green fodder	Milk, grass and soil samples are to be taken as far as possible at the same time and at the same place
		b) Specific activity of single nuclides determined by γ-spectrometry	185 mBq/l	b) Sampling at a farm with milch cows in the area of the least favorable point of impact and at a dairy	b) Twice a year during the period of green fodder	
		c) Specific I-131 activity	18.5 mBq/l	c) Sampling at a farm with milch cows in the area of the least favorable point of impact and at a dairy	c) Monthly during the period of green fodder	
2.2	Grass	Specific activity of single nuclides determined by γ-spectrometry	740 mBq/kg related to Co-60 and dry matter	1 sampling location in the area of the least favorable point of impact and at a reference point	Respectively two random samples per year of the first and second hay harvest	Milk, grass and soil samples are to be taken as far as possible at the same time and at the same place
2.3	Soil	Specific activity of single nuclides determined by γ-spectrometry	370 mBq/kg related to Co-60 and dry matter	1 sampling location in the area of the least favorable point of impact and at a reference point	2 random samples per year	
2.4	Foodstuff	a) Sr-90 activity	37 mBq/kg related to fresh matter	Many sampling locations, preferably of the area of impact least favorable and of a reference area	Samples of harvest-ripe products	Random samples preferable of free-land and leaf vegetables, fruit and corn, as far as possible dispersed over the whole year
		b) Specific activity of single nuclides determined by γ-spectrometry	370 mBq/kg related to Co-60 and fresh matter	Many sampling locations, preferably of the area of impact least favorable and of a reference area	Samples of harvest-ripe products	Random samples preferable of free-land and leaf vegetables, fruit and corn, as far as possible dispersed over the whole year

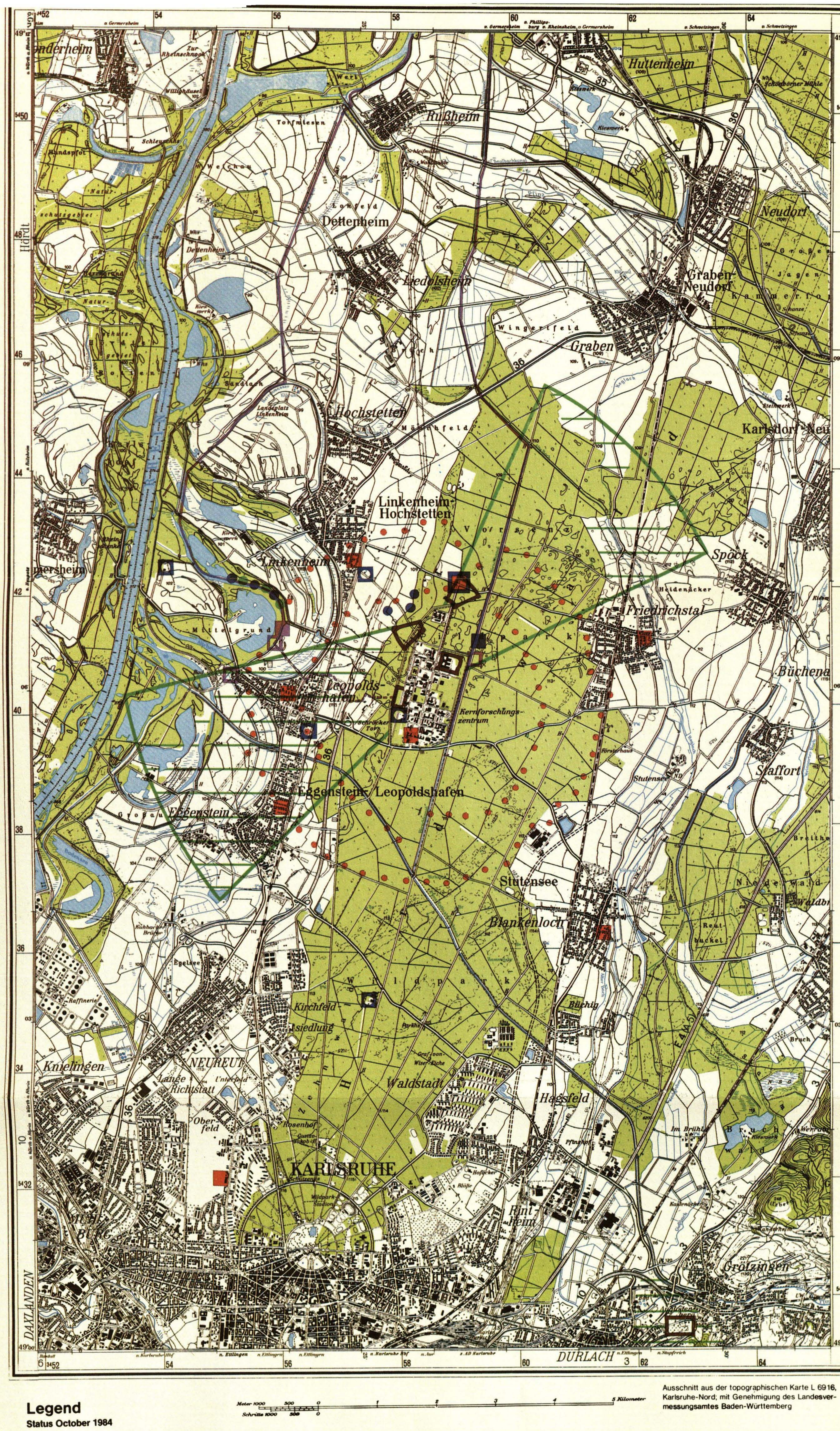
Table 3: Environmental monitoring of a NPP by the authority. Program for normal operation.

Program item	Monitored medium and monitored type of radiation, respectively	Measured variables	Required detection limit	Sampling and measuring locations, respectively	Type and frequency of samplings and measurements	Remarks
3.	WATER AND FOOD CHAINS IN WATER					
3.1	Surface water	a) Tritium activity	185 Bq/l	a) 1 sampling location each in the inlet and outlet building	a) Continuous sampling during a period of one month and quarterly evaluation	
		b) Residual ß-activity	110 mBq/l related to K-40	b) 1 sampling location each in the inlet and outlet building	b) If residual ß-activity > 370 mBq/l then measurement according to 3.1.c	
		c) Specific activity of single nuclides determined by γ-spectrometry	74 mBq/l related to Co-60	c) 1 sampling location each in the inlet and outlet building	c) Continuous sampling during a period of one month and quarterly evaluation	
3.2	Fish meat	Specific activity of single nuclides determined by γ-spectrometry	370 mBq/kg related to fresh matter and Co-60	1 sampling location each in the area of the building of outlet and downstream the power plant	Semi-annual random samples and semi-annual evaluation	Special ecological conditions specific to location have to be considered for monitoring
3.3	Sediment	Specific activity of single nuclides determined by γ-spectrometry	18.5 Bq/kg related to dry matter and Co-60	1 sampling location each in the area of the building of outlet as well as up- and downstream the power plant	Semi-annual taking of random samples with evaluation	Special ecological conditions specific to location have to be considered for monitoring
3.4	Drinking water	a) Specific activity of single nuclides determined by γ-spectrometry	74 mBq/l related to Co-60	a) Samplings out of a nearby fountain which is used for the supply of drinking water	a) Quarterly taking of random samples with evaluation	a) Monitoring only, if a fountain in the environment of the nuclear power plant is used
		b) Sr-90 activity	74 mBq/l	b) Waterwork downstream the power plant	b) Semi-annual evaluation of the sample, obtained within a period of collecting of half a year	b) Only waterworks preparing surface water or filtrate of river banks (sampling preferably carried out with evaporation collector)
		c) Specific activity of single nuclides determined by γ-spectrometry	74 mBq/l related to Co-60	c) Waterwork downstream the power plant	c) Semi-annual evaluation of the sample, obtained within a period of collecting of half a year	c) Only waterworks preparing surface water or filtrate of river banks (sampling preferably carried out with evaporation collector)

Table 3: cont. Environmental monitoring of a NPP by the authority. Program for normal operation.

Program item	Monitored medium and monitored type of radiation, respectively	Measured variables	Required detection limit	Sampling and measuring locations, respectively	Type and frequency of samplings and measurements	Remarks
4.	AIR AND SOIL					
4.1	γ-radiation	Local γ-dose	0.5 mSv/a	20 solid-state dosimeters	Annual evaluation	
4.2	γ-radiation	Local γ-dose rate	0.1 μSv/a	Semi-annually changing measuring locations at the selected places in the zones and sectors in the environment of the nuclear power plant	Semi-annually short-term measurements	Measures at the periodical measuring travel
4.3	Aerosols	β-gross activity	3.7 Bq/m^3	Semi-annually changing measuring locations at the selected places in the zones and sectors in the environment of the nuclear power plant	Semi-annually random samples and evaluation in the measuring car	Measures at the periodical measuring travel
4.4	Gaseous iodine	Specific I-131 activity	3.7 Bq/m^3	Semi-annually changing measuring locations at the selected places in the zones and sectors in the environment of the nuclear power plant	Semi-annually random samples and evaluation in the measuring car	Measures at the periodical measuring travel
4.5	Soil surface	β-gross activity	3.7 kBq/m^2 related to K-40	Semi-annually changing measuring locations at the selected places in the zones and sectors in the environment of the nuclear power plant	Semi-annually short-term measurements	Measures at the periodical measuring travel

Table 3: cont. Environmental monitoring of a NPP by the authority. Program for accidents.



Ausschnitt aus der topographischen Karte L 6916, Karlsruhe-Nord; mit Genehmigung des Landesvermessungsamtes Baden-Württemberg

Legend
Status October 1984

- COUNTING TUBE FIELD STATION
- SOLID STATE DOSIMETERS
- AEROSOLS
- DRINKING WATER (WATERWORKS)
- GROUND WATER (OBSERVATION WELLS)
- SURFACE WATER
- PLANKTON AND CONTINUOUS SAMPLING OF SURFACE WATER
- SLUDGE
- FISH AND WATER PLANTS
- LIQUID EFFLUENT FEED PIPE TO THE MAIN CANAL (ALTRHEIN)
- COURSE OF SURFACE WATERS SERVING AS MAIN CANALS
- SOIL
- AGRICULTURAL PRODUCTS
- MAIN WIND DIRECTION SECTORS

Site Map of the Measurement and Sampling Locations for Environmental Monitoring of the Karlsruhe Nuclear Research Center

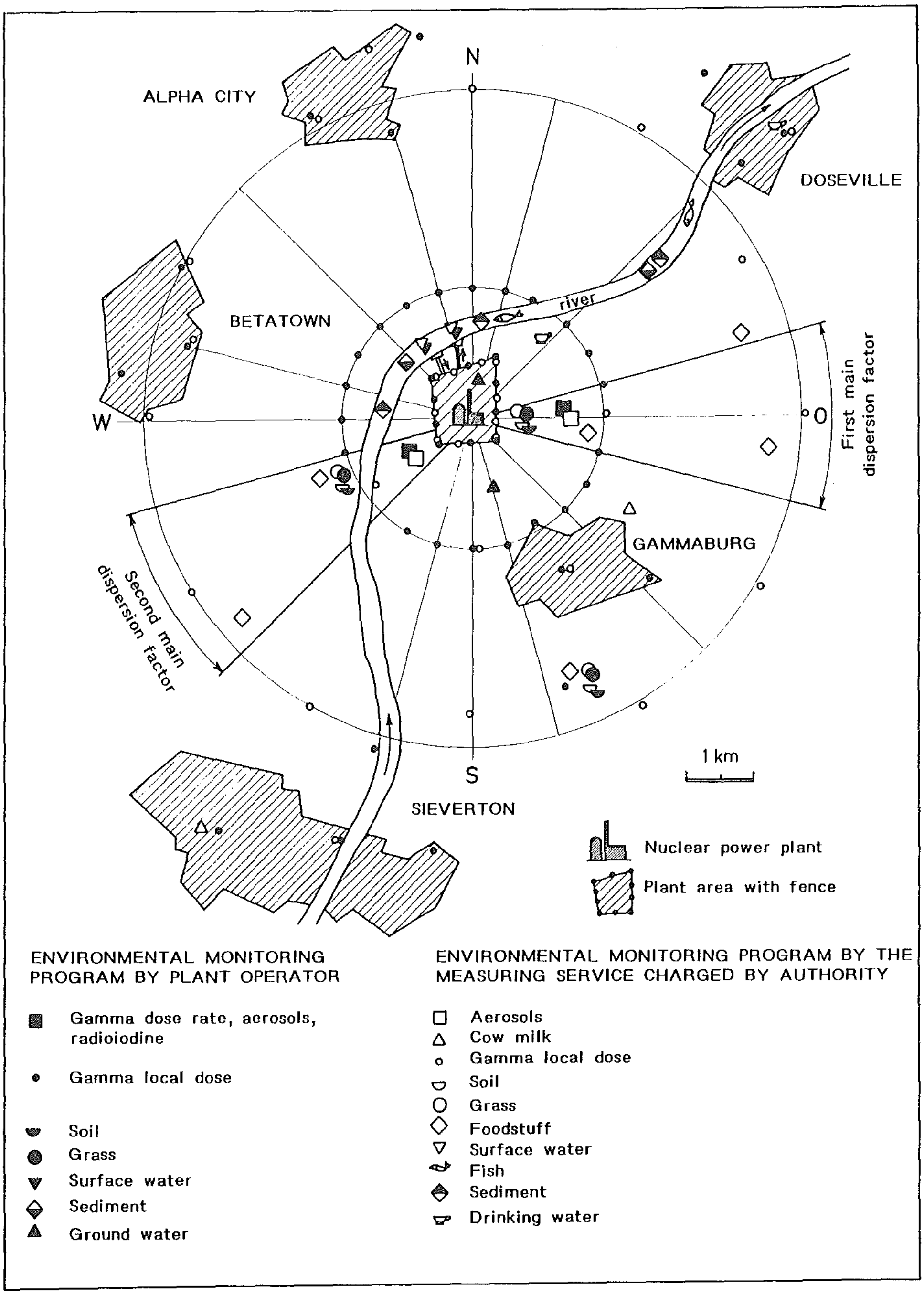


Fig. 3: Environmental monitoring program for a nuclear power plant.

6. RESULTS OF ENVIRONMENTAL MONITORING OF NUCLEAR POWER PLANTS IN THE FEDERAL REPUBLIC OF GERMANY

Since 1958, data on environmental radioactivity from measurements by authorized laboratories have been published in the Federal Republic of Germany in quarterly reports and since 1968 in annual reports. In addition to the results from environmental monitoring, these reports include data on population exposure due to natural and artificial sources. Information is given on radiation exposure from

- natural radiation sources,
- medical application,
- nuclear installations,
- handling of radioactive substances and ionizing radiation,
- occupational exposure,
- nuclear weapons tests,
- radioactive waste,
- radiation accidents and particular incidents.

The 1983 report on "Environmental Radioactivity and Radiation Exposure" published by the Federal Ministry of the Interior in 1985 has 388 pages. This report contains a wealth of tables of activity concentrations in different media and details of the release of radionuclides from nuclear installations (Tables 4-6).

Releases of radioactive substances from nuclear installations produce only an insignificant increase in the radiation exposure of the population (Tables 7 and 8). The upper values of the radiation exposure of individuals from these emissions, calculated according to the basic calculation principles valid in the Federal Republic of Germany, are clearly below the dose limits specified in the Radiation Protection Ordinance and are considerably lower than the width of variation of natural radiation exposure in the Federal Republic of Germany.

	Obrigheim	Stade	Biblis A	Biblis B	Neckarwestheim	Unterweser	Grafenrheinfeld
Cr 51	3,1 E7				1,2 E7		
Mn 54	4,1 E7	1,2 E7	9,0 E6	1,1 E6	8,7 E5		
Fe 59							
Co 57							
Co 58	4,0 E8	7,0 E7	2,7 E7	6,1 E7	6,2 E6	3,8 E7	3,6 E7
Co 60	1,4 E9	4,7 E8	9,3 E8	6,4 E8	5,4 E7	6,7 E7	2,6 E7
Zn 65	8,5 E5						
Sr 89	3,9 E6		2,7 E6	1,3 E6	8,8 E4		
Sr 90	2,3 E6	8,8 E5	4,6 E6	1,3 E6			1,7 E6
Zr 95						2,1 E6	
Nb 95	5,2 E6	1,7 E6			5,8 E5	1,9 E6	
Ru 103		7,0 E5					
Ru 106		2,2 E6			2,0 E6		
Ag 110m	8,1 E7	9,4 E7	3,0 E5		8,0 E6		
Te 123m		4,1 E7	5,6 E7	2,0 E7	6,5 E6		1,9 E7
Sb 122							
Sb 124	7,0 E6	6,0 E7	2,2 E8	8,6 E7	8,4 E6	3,3 E8	1,3 E7
Sb 125				8,9 E6	1,3 E6		
I 131	2,0 E8		3,3 E7	3,3 E7	1,7 E6		1,8 E6
Xe 133	3,3 E8						
Cs 134	5,1 E7	4,1 E7	2,9 E8	1,8 E7	4,9 E6	3,9 E7	
Cs 137	4,1 E8	3,4 E8	5,7 E8	1,3 E8	3,5 E6	1,7 E8	
Ba 140			1,1 E7				
La 140	2,1 E6	2,8 E6	1,2 E8				
Ce 141							
Ce 144			6,0 E5		6,7 E6		
Sum	2,9 E9	1,1 E9	2,3 E9	9,9 E8	1,2 E8	6,5 E8	9,8 E7

Table 4: Activation and fission products in liquid effluents from german nuclear power plants with PWR, 1983.

Nuclear power plant	Activation and fission products GBq	H-3 TBq
Obrigheim	2.9	3.2
Stade	1.1	8
Würgassen	6.2	0.4
Biblis A	2.3	21
Biblis B	1.0	15
Neckarwestheim	0.1	11.8
Brunsbüttel	0.9	1.1
Isar	0.5	3.1
Unterweser	0.7	19.2
Philippsburg	3.3	1.7
Grafenrheinfeld	0.01	19
Krümmel	1.3	0.04

Table 5: Activity in liquid effluents, 1983.

Nuclear power plant	Noble gases Bq	Aerosols Bq	I-131 Bq	C-14 Bq	H-3 Bq
Obrigheim	1.7 E13	1.2 E08	5.6 E07	4.0 E10	1.8 E11
Stade	1.8 E12	2.7 E08	5.4 E06	1.3 E11	1.5 E12
Würgassen	2.3 E13	2.1 E09	7.6 E08	1.5 E10	5.2 E10
Biblis A	3.5 E12	1.0 E09	1.2 E08	4.1 E10	1.7 E12
Biblis B	1.5 E13	7.4 E06	2.7 E07	2.2 E10	6.4 E11
Neckarwestheim	5.0 E12	1.5 E08	7.9 E06	2.6 E10	8.0 E11
Brunsbüttel	1.9 E12	5.9 E07	6.4 E06	8.8 E08	1.4 E10
Isar	2.2 E13	4.3 E08	3.1 E06	3.4 E11	5.7 E11
Unterweser	6.0 E12	1.4 E07	5.0 E06	2.2 E10	1.6 E12
Philippsburg	2.8 E13	3.7 E07	2.1 E09	2.0 E11	2.0 E11
Grafenrheinfeld	7.4 E12	3.5 E05	4.6 E04	3.1 E11	2.3 E11
Krümmel	8.1 E09	1.3 E05	2.7 E04	-	7.5 E09

Table 6: Activity in airborne effluents, 1983.

Nuclear power plant	Maximum whole body exposure (adult) µSv	Maximum thyroid exposure (infant) µSv	Average gonad dose of the population	
			0-3 km µSv	0-20 km µSv
Kahl	1	1	0.04	< 0.01
Obrigheim	2	10	0.2	0.01
Stade	0.2	0.2	0.03	< 0.01
Würgassen	2	8	0.2	0.02
Biblis	0.4	2	0.06	< 0.01
Neckarwestheim	0.1	< 0.1	0.01	< 0.01
Brunsbüttel	0.1	0.1	< 0.01	< 0.01
Isar	0.3	0.3	0.05	< 0.01
Unterweser	0.1	< 0.1	< 0.01	< 0.01
Philippsburg	0.8	70	0.04	< 0.01
Grafenrheinfeld	0.1	0.1	0.01	< 0.01
Krümmel	< 0.1	< 0.1	< 0.01	< 0.01

Table 7: Radiation exposure due to airborne effluents, 1983.

Nuclear power plant	Maximum whole body exposure (adult) µSv	Average whole body exposure (public) µSv
Kahl	0.3	< 0.1
Obrigheim	0.2	< 0.1
Stade	0.1	< 0.1
Würgassen	1	< 0.1
Biblis	0.1	< 0.1
Neckarwestheim	0.4	< 0.1
Brunsbüttel	0.1	< 0.1
Isar	0.1	< 0.1
Unterweser	0.2	< 0.1
Philippsburg	0.4	< 0.1
Grafenrheinfeld	0.4	< 0.1
Krümmel	0.2	< 0.1

Table 8: Radiation exposure due to liquid effluents, 1983.

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CLOSING REMARKS

by Iyos Subki, DDG-BATAN

Distinguished delegates from FRG, seminar's participants, Ladies and Gentlemen :

It is indeed a great honour for me to be given an opportunity to say a few words of closing remarks.

This joint Indonesian-German Seminar on Public Acceptance, Waste Management and Nuclear Safety is not only timely but also of great importance in securing the strong foundation for nuclear technology in Indonesia.

A well founded technology, be it nuclear or conventional, always gives full and in-depth considerations on the safety of mankind and environment. This is exactly the characteristics of nuclear technology!. Otherwise, a technology will be called inadequate and therefore considered unacceptable to us.

In various occasions, BATAN as governmental body in its function to develop safe nuclear technology, has expressed its political determination and will to improve the safety of nuclear energy systems in Indonesia. This seminar, in fact, manifests our commitment and our irrevocable responsibility to secure nuclear safety, human health and environmental protection.

Before going further, may I say a few words about the present seminar.

This joint seminar has been made a reality thanks to the support of German Ministry for Research and Technology (BMFT) who has succeeded to mobilize and send a mission of German nuclear experts to Jakarta. In this venture, I must say that the role of Bapak Nentwich of KFA is really outstanding.

Meeting on progress eval.

In this opportunity, allow me also to express my sincere congratulations and appreciations to the German experts for their inspiring, well planned and well presented papers. We are of the opinion that your ideas and thoughts are of great importance to our programme in improving and strengthening nuclear safety and radiological protection in Indonesia. And let me assure all of you that we are not being complacent in these strategic endeavours.

Ladies and Gentlemen :
What are the major critical issues in nuclear energy at the present time ? The answer is :

Nuclear safety,
radiological hazards and
radioactive waste management.

In this seminar the experts and the participants have discussed comprehensively the above three problems in an open and honest manner. And, ofcourse, we are convinced that the problems are not insurmountable. The technology is available to solve the problems, what is needed now is a strong political determination to reach our safety goal.

The unfortunate accident at Chernobyl has indeed had a negative effect on public opinion and increased the number of people scepticle about or frightened by nuclear power.

We, as scientists and engineers, urge everybody not to be too emotional and jump up to negative conclusions.

A week-long meeting was convened by IAEA in Vienna last August and attended by more than 500 nuclear experts from all over the world to discuss and review in detail the report by Soviet experts on the Chernobyl accident.

We have learned from that meeting, and as discussed also in this seminar, the following facts about the consequences of the accident : the number of casualty up to now is 31 and according to calculations by authoritative experts the possible number of additional cancer cases due to radiation exposure in the next 70 years is between 5000 and 20000. This means 0.1% of the possible number of cancer cases (due to all causes) in the same population during the same period.

We know also that the accident at Chernobyl is specific to this type of reactor, that is RBMK or Light Water Graphite Moderated Reactor (LWGR), which has a core configuration enabling a fast reactivity transient due the positive void coefficient. Ofcourse, this is not the only weakness.
Nevertheless, we, as good students, can learn many lessons and answer many questions from the accident. It is also encouraging that the Soviet authorities have taken several measures in the right direction with the aim of preventing any recurrence.

So, ladies and gentlemen, if we exercise some reflections on the performance of nuclear power plants, there should be no question with regard to the acceptability of nuclear power as an economic source of energy, especially electricity.

Just remember: that before Chernobyl, nuclear electricity generation had logged 4000 reactor years of experience without a single death due to accident or radiation. Ofcourse, this record will be very much improved in the comming years especially outside the Soviet.

Remember also that today, 15% of the electricity is generated by NPP (this is equivalent to 7 million BOE per day) and by 1990 it will be 20%.

We may repeat again that nuclear power is a safe and viable energy source. That nuclear power is not a luxury, like lisptick for a lady of which she can do without.

This idea is also supported by the leaders of seven industrialized countries in their last meeting in Tokyo (just after Chernobyl accident) who declared that 'properly managed" nuclear power will continue to produce an increasing share of the world's electricity.

Coming back to the discussion in this seminar, and in congruence with our commitment to the highest standard of safety, I believe that the future direction in nuclear safety will be a more concentrated effort on design features that tolerate human error (forgiving design), technical devices designed to prevent the off-site consequences, computerized operational aids and a much better education of operators.

Ladies and Gentlemen :

I would like now to touch upon Indonesia's international responsibility in nuclear safety, I can inform you that our government has signed two International Conventions in Vienna, subject only to ratification by our parliament.

The conventions are : Conventions on Early Notification of a Nuclear Accident and Assistance in the Case of a Nuclear Accident or Radiological Emergency.

These are essentially conventions on actions by nations in case of accidents with potential transboundary effects.

We discussed also about nuclear standards in this seminar, the existing IAEA nuclear safety standards (NUSS) is highly respected and often incorporated in national legislation. What we are heading at right now in the international dimension is a "binding international safety standards" which will be adopted by every nation including the Soviets. This, ofcourse, will take sometime. But it is exhilarating to note that Mr. Gorbachev has called for an "international safety regime".

At this juncture, ladies and gentlemen, I would like to express my satisfaction for the conduct of the seminar, for the issues discussed by the experts and for the active participation of the audience. It is my hope that this seminar will be continued with a more intensive cooperation between our two countries.

In conclusion, may I wish the distinguished German delegates an enjoyable visit in Indonesia and a safe journey to Germany.

I thank you !

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